SEEKING CRITERIA FOR BIODIVERSITY ROOFS UNDER FINNISH CONDITIONS

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Urbanisation has caused many environmental problems, such as air pollution and the loss of biodiversity. One way to mitigate these problems is to expand green spaces. Roofs, as the last frontier, could be made full use of. Green roofs have become a hot topic in recent years. In this study, I investigated the ability of green roofs to support urban biodiversity by conducting a literature review, and then I sought the criteria for biodiversity roofs under Finnish conditions by interviewing ecologists.

My research questions in this study were 1) What kinds of habitats could be "ideal ecosystems" to be mimicked on biodiversity roofs in Finland; 2) which plant species could exist on roofs and whether they contribute to biodiversity; 3) what kinds of substrates support the biodiversity on roofs; 4) whether green roofs support faunal diversity and what faunal taxa could exist on roofs; 5) if and how roof structural characteristics influence roof biodiversity; 6) what kinds of management are practiced on biodiversity roofs; 7) what are people's attitudes towards or perceptions of biodiversity roofs in general.

In this study, I conduct that 1) Sunny dry habitats, such as meadows and tundra, can be regarded as "model ecosystems" for biodiversity roofs in the Finnish context. 2) Substrate heterogeneity is a key to biodiversity on green roofs. Different materials and different combinations of materials could be applied on the same roof to mimic diverse types of soil types in the most biodiverse Finnish ecosystems. 3) Native species from the model ecosystems are ideal plants for biodiversity roofs. Combining multiple greening methods on the same roof can be a solution to achieve "instant greening effects" with only native species. 4) An ideal biodiversity roof in the Finnish context could support birds, bats, and invertebrates, such as spiders. To attract and support fauna, a roof needs a diverse plant community, as well as extra elements, such as deadwood. 5) Roof structural characteristics (i.e. roof height, size, slope, direction, location, and age) impact biodiversity by determining the accessibility to and the dispersal of flora and fauna, as well as microclimates on roofs. 6) Management, such as irrigation, might help biodiversity at least for newly established biodiversity roofs, but biodiversity roofs aim at being self-sustaining eventually. 7) People have generally positive attitudes towards green roofs, but their willingness to actually install a biodiversity roof is influenced by other issues, such as the financial cost and roof safety.

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1 Introduction

Currently, more than half of the world's population live in urban areas (United Nation 2015). Many environmental problems, such as the urban heat island effect, air pollution, and urban runoff water contamination, have arisen due to urbanisation and the consequent fragmentation, and shrinking green space (Gromaire-Mertz et al. 1999, Weng et al. 2004, Debbage & Shepherd 2015). These problems influence the ecology of cities as well as human well-being both physically and psychologically. For example, air pollution is likely to increase respiratory symptoms and cardiovascular disease, and decrease lung function (Künzlia & Tagerb 2005, Götschi et al. 2008, Franchini & Mannucci 2012). Some studies have shown that urbanisation increases the risks of stress and mental disorder (Marsella 1998, Sundquist et al. 2004, Peen et al. 2007). The fragmentation of large and continuous green spaces into small and isolated patches also resulted in biodiversity loss and homogenization of urban ecosystems, which leads to people's disconnection to nature (Miller 2005).

Biodiversity is important to both the ecology of cities and human well-being. Biodiversity refers to the variety of life at all levels, i.e. genetic diversity, species diversity, and ecosystem diversity (State of the Environment 2011 Committee 2011). Biodiversity contributes to the resilience and stability of ecosystems, as species have overlaps in ecological functions; thus removing a species from a biodiverse ecosystem may not influence its ecological functions due to the existence of other species with similar functions (Peterson et al. 1998).

Biodiversity is beneficial to human well-being physically and mentally. A study in Finland showed an association between allergic diseases, environmental biodiversity, and human microbiota, meaning that biodiversity contributes to the development of our immune systems (Hanski et al. 2012). Fuller et al. (2007) demonstrated that exposure to urban green space with high biodiversity in the U.K. had positive effects on people's mental well-being. A study in Australia revealed that native biodiversity that has endemic characteristics in a given geographic area can contribute to the sense of place that is a crucial factor affecting well-being (Horwitz et al. 2001). Furthermore, personal experiences of biodiversity shape people's perceptions of biodiversity that indirectly influence policy decisions on nature conservation (Dearborn & Kark 2010).

One way to abate problems due to the loss of biodiversity in urban areas could be to create new green spaces to support the existing ones. Roofs, as the "last urban frontiers" with walls, ought to be fully utilised to allow green space to expand in urban contexts (Peck 2002). Green roofs, as a promising solution, have been widespread throughout Europe (Peck 2002). Green roofs refer to "vegetative roof systems that contain live plants atop the roof membrane" (Cavanaugh 2008) and have been argued to be able to enhance urban biodiversity by providing habitats for both plants and animals (e.g. Berndtsson 2010, Williams et al. 2014).

Green roofs with high species richness generally have high functional diversity, contributing to a sustainable ecosystem (Van Mechelen et al. 2015). Biodiverse green roofs might more or less reduce problems caused by the loss of biodiversity, although they cannot fully compensate for other already existing ground level green spaces, such as forests (Currie & Bass 2008).

The initial term used to describe green roofs with high biodiversity was "brown roof" (Jones 2002). Brown roofs were initially designed to mimic brownfields to provide feeding habitats for Black Redstart (*Phoenicurus ochruros*), a rare species in the U.K. but common in continental Europe (Gedge 2003), from where it spread to the U.K. in the 19th century (Grant 2006). Black Redstart is insectivorous and survives on brownfields that are often high in biodiversity, providing habitats for invertebrates, such as beetles, leafhoppers, and grasshoppers (Gedge 2003, Eyre et al. 2003, Strauss & Biedermann 2006). Yet there are other types of green roofs that have high or relatively high biodiversity; thus, newer studies have also used terms "biodiversity roof" or "biodiverse roof" (e.g. Gedge 2003, Olly et al. 2011).

There are different ways to classify green roofs. Green roof industry often divides green roofs according to the substrate depth. This “industrial typology” divides green roofs into three types, i.e. “extensive”, “semi-extensive”/ “semi-intensive”/ “simple intensive”, and “intensive” green roofs (Mentens et al. 2003, Peck & Kuhn 2003). To compare, Madre et al. (2014) used an “ecological typology” dividing green roofs to “muscinal”, “herbaceous”, “arbustive”, and “arboreous” according to vegetation types (Table 1). However, the classification of green roofs is inconsistent and it is unclear how biodiversity fits into these typologies. Furthermore, it seems that studies about roof biodiversity *per se* are rather few and scattered, meaning that we do not yet know what is actually meant by the biodiversity roof or the factors that influence biodiversity on roofs.

Table 1 Industrial and ecological typological systems of green roofs (According to Mentens et al. 2003, Peck & Kuhn 2003, Madre et al. 2014).

Industrial typological system	Substrate Depth	Ecological typological system	Vegetation type and plant height at maturity
Extensive	5-15cm	Muscinal	bryophytes, lichens, fungi, and small herbaceous plants
Semi-extensive or Semi-intensive or Simple intensive	15-25cm	Herbaceous	non-woody herbaceous plants (>1m in height)
		Arbustive	shrubs, bushes, young trees (1-7m in height)
Intensive	20 (or 25) - 60cm	Arboreous	large trees (> 7m in height)

In this thesis, I provide a review of current knowledge related to biodiversity on roofs to clarify the factors impacting green roof biodiversity. My main aim was to find the criteria for biodiversity roofs under Finnish conditions. I approached this aim with two steps: In the first step, I explored if existing research literature gives evidence that green roofs enhance urban biodiversity, and if they do, how they support urban biodiversity. In the second step, I interviewed ecologists about what they think a “biodiversity roof” in the Finnish context could be like.

More specifically, my research questions were 1) What kinds of habitats could be “ideal ecosystems” to be mimicked on biodiversity roofs in Finland; 2) which plant species could exist on roofs and whether they contribute to biodiversity; 3) what kinds of substrates support the biodiversity on roofs; 4) whether green roofs support faunal diversity and what taxa could exist on roofs; 5) if and how roof structural characteristics influence roof biodiversity; 6) what kinds of management are practiced on biodiversity roofs; 7) what are people’s attitudes towards or perceptions of biodiversity roofs in general.

2 Material and Methods

2.1 Literature Review

I conducted a literature review, into which I included research papers and reviews from scholarly journals dealing with green roofs and biodiversity. In addition to peer-reviewed papers, I decided to include conference papers, since biodiversity on green roofs is a rather new topic and conference papers could contain new information on the topic in English.

I started the literature search with keywords "green roof" AND "biodiversity" to search for empirical studies and literature reviews on biodiversity roofs through three most popular search engines (Web of Science, Scopus, and Google Scholar). I searched papers written in English up until the end of June 2015. There were 53 results in Web of Science, 77 results in Scopus, and 2870 results in Google Scholar. Most of the hits in Google Scholar, however, were irrelevant to the topic according to their titles and abstracts, dealing actually with stormwater and energy but not biodiversity per se. Thus, I repeated the search by using the "Advanced Scholar Search" function to exclude articles with words "stormwater" and "energy", which resulted in 221 hits.

I also searched keywords "ecoroof" AND "biodiversity", "living roof" AND "biodiversity", and "vegetated roof" AND "biodiversity" respectively in the three search engines, since "ecoroof", "living roof", and "vegetated roof" are synonyms to the term "green roof". However, all of the relevant hits were found in the result of the search with the keywords "green roof" AND "biodiversity". Thus I only used "green roof" AND "biodiversity" in this thesis.

In addition to articles that were directly relevant to biodiversity and green roofs, the hits of the three search engines included articles about people's perceptions and/or attitudes towards a green roof and its biodiversity. I included them in my literature review, as I thought they could bring some new aspects to the understanding of what is meant by biodiversity roofs. 40 hits on Web of Science, 48 hits on Scopus, and 41 hits on Google Scholar met my requirements for biodiversity and green roofs, and people's attitudes. 5 articles on Google Scholar seemed to be related to the topic according to their title and abstract, but were unavailable and thus excluded from this review. 29 relevant papers were "double shots", i.e. hit by two search engines, and 6 relevant papers were hit by all the three engines. Altogether, 84 papers about green roofs and biodiversity were used, and 4 hits in the search were relevant to people's perceptions and attitudes towards green roofs in general instead of biodiversity on roofs per se.

Furthermore, to ensure all the relevant papers were included in the review, I searched for more papers with keywords "green roof" AND ("people's perception" OR "attitudes and aesthetic") in the three search engines. Search in Google Scholar resulted in 4 relevant new hits out of 15 results in total, but no relevant articles were hit in the other two search engines. Moreover, I traced 50 articles concerning biodiversity per se from the references in the searched papers that were not found through the search engines.

After reading carefully through all the relevant hits and the traced references, I ended up in including 142 papers in the review (Appendix 1 and 2). Of these 142 papers, 92 were searched through the search engines, and 50 papers were traced references. 134 papers were about biodiversity and green roof, and 8 papers were about people's perceptions of green roofs.

2.2 Interview

I designed a semi-structured interview including 20 questions based on the main themes found from the literature review (Appendix 3). I interviewed 8 people who were experts on bryophytes, vascular plants, microbes, carabids and sunny habitats, pollinators, spiders, birds, and soil science. Seven interviews were carried out in English and one was done in Chinese. Each interview lasted 30 – 50 minutes. I recorded all the interviews with the permit of the interviewees and analysed the interviews according to the transcripts of the recording. The transcripts were altogether 55 pages in English and 4 pages in Chinese with font size 12 and line spacing 1.5.

I did the content analysis manually. I read all the transcripts eight times. The first time was to get an overall view of the responses and to decide how to analyse the transcripts. I decided to build thematic categories, referring to specific topics in this thesis (Kuckartz 2014). I classified all information from the 20 questions into seven main themes. After the initial going through of the transcripts, I read all the data seven more times to pick out relevant contents to each theme. The data was recorded into Excel and presented as narrative text in this thesis.

3 Results

3.1 Results of the Literature Review

The number of empirical research papers published generally increased from 2001, when the first paper in this review was published, to June 2015 (Figure 1). Most of the research papers were about vegetation (Figure 2).

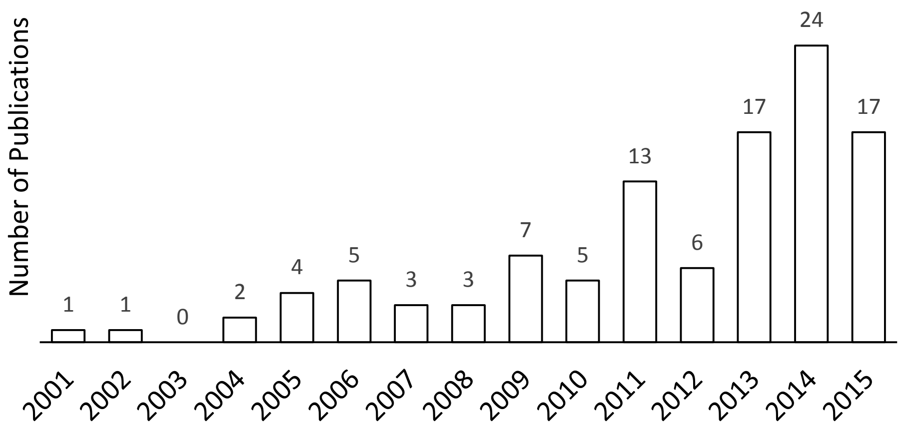

Figure 1 Yearly number of published empirical research papers on green roofs and biodiversity (2001 - June 2015).

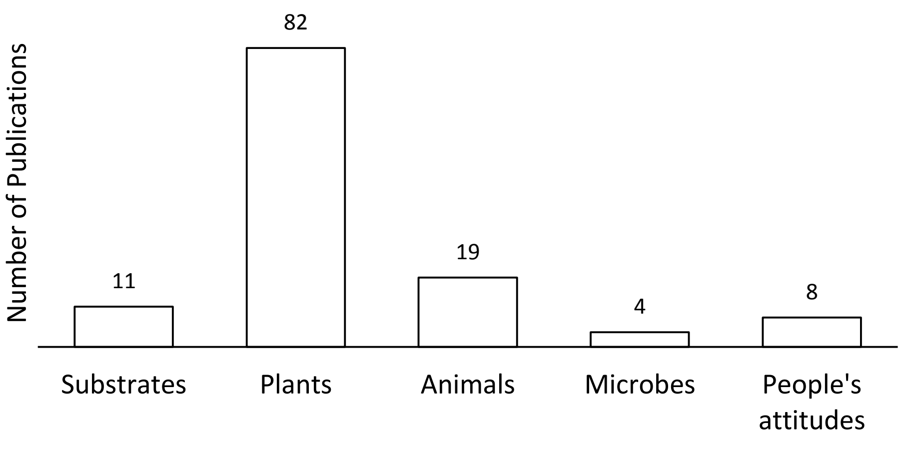

Figure 2 Study topics of the 108 empirical research papers. Seven papers focused on both plants and substrates, and five papers were on both plants and animals, which explains why the total number exceeds 108.

3.1.1 Substrates Used on Green Roofs and Their Impacts on Plants

Most of the reviewed papers provided some information about materials used as green roof substrates, although only 11 papers were specifically studies on substrates, and/ or their effects on plants.

Substrate Materials. According to the literature review, the general requirement for green roof substrate materials was that they should be light, well-drained, and prone to extreme fluctuations in moisture content, as these characteristics are among the most critical factors influencing green roof installation and plant growth (Bousselot et al. 2011). A wide range of substrate materials was utilised in the reviewed papers. These materials could be generally divided into mineral (e.g. soil, rock, gravel, rubble, and sand) and organic materials (e.g. loamy mulch, compost, and green organic waste matter, see Appendix 2). Rubble seemed to be the most frequently used mineral material as the substrate base; it mainly refers to crushed brick and concrete, and sometimes also crushed tiles (e.g. Gedge & Kadas 2005, Graceson et al. 2014). There was not a single prevailing organic material mentioned in the reviewed papers.

Materials Combinations. Most studies on this topic were done with different combinations of mineral and/or organic substrate materials (e.g. Benvenuti 2014, Zhao et al. 2014). The combinations of different substrate materials were found to affect vegetation differently. A high percentage of crushed brick in growing media contributed to diverse wildflower vegetation, while solid municipal waste incinerator bottom ash aggregate led to a poor performance of vegetation and was not recommended for biodiversity roofs (Bates et al. 2015a). Furthermore, Bates et al. (2015a) found that although the species richness varied significantly, the plant biomass was similar in treatments with different substrate materials; in the treatments with a sparse cover of forb species, sedums had an opportunity to increase its coverage and biomass.

The content of organic matter combined in green roof substrates has received attention from researchers due to its high water holding capacity in general. For example, Nagase and Dunnett (2011) mixed different amounts of organic matter (0%, 10%, 25%, and 50% by volume) and found out that in wet regimes the organic matter content was positively correlated with the vegetation growth. Under dry conditions, however, the treatment with 10% organic matter was optimal for the four studied species, Chives (*Allium schoenoprasum*), Sea Lavender (*Limonium latifolium*), Hairy Melic (*Melica ciliata*), and Catmint (*Nepeta* × *faassenii*), since a lush growth caused in a wet watering regime might not bear a sudden environmental change (Nagase & Dunnett 2011). Moreover, Thuring and Dunnett (2014) found that the substrate depth would reduce dramatically if organic matter content at the starting point was high.

Particle Size of Substrates. The particle size of substrates influences plant performance. Young et al. (2014) found that different particle sizes of the same substrate material could bring about differences in vegetation growth. In their study, the shoot growth of Ryegrass (*Lolium perenne*) was 17% less when it grew on an aggregate consisting of large brick particles (diameter 4 – 15 mm diameter) compared to growing on small brick particles (diameter 2 – 5 mm in diameter). Young et al. (2014) suggested a likely reason that compared to small brick particles, large brick particles had a lower water holding capacity due to smaller inner particle pore space, which may expose vegetation to water stress during extreme drought. Thus, under dry climate conditions, small particles may supply adequate water to plants without extra irrigation due to their high water holding capacity, while large particles can suit regions with a large amount of precipitation to adapt to local climate (Young et al. 2014).

Substrate Depth. Substrate depth impacts plant diversity and performance, but it is debatable if deep substrates unambiguously have a positive effect on plant species. Some studies showed that plants grew better in deep substrates. For example, when water supply on roofs was restricted, a 10 cm substrate depth enhanced the drought tolerance of plants, as compared to 4 cm and 7 cm substrates depths (Lu et al. 2015). However, Nektarios et al. (2015) reported that

Pale Stonecrop (*Sedum sediforme*) benefited from water in a shallower substrate (7.5 cm) rather than a deeper substrate (15 cm) during the first water-stress period. A likely explanation is that increasing substrate depth did not benefit plant performance without additional irrigation (Dunnett & Nolan 2004). Boivin et al. (2001) found that deeper substrates might benefit some but not all plant species: the winter damage severity of three out of six plant species decreased significantly when deeper substrates (10 cm and 15 cm) were used compared to thin substrates (5 cm).

According to the reviewed papers, the most likely reason for this ambiguous impact of substrate depth on plants is that different plant species favour different substrate depths. Heim and Lundholm (2014a) studied Red Fescue (*Festuca rubra*) and Goldmoss stonecrop (*Sedum acre*), a native grass and a succulent growing in Canada. The two species were found to prefer different substrate depths: *F. rubra* had a significantly higher relative growth rate in substrates that were either 10 or 15 cm deep compared to 5 cm, while *S. acre* had significantly higher relative growth rate in substrates that were 5 cm deep than those of 10 and 15 cm (Heim & Lundholm 2014a). Dunnett et al. (2008a) studied 15 planted species and 20 self-seeded species on roofs. Among the 35 species, plants, such as Birdeye Speedwell (*Veronica persica*) and Shepherd's Purse (*Capsella bursa-pastoris*), appeared to have greater affinity or occurred only at the substrate depth of 10 cm, while species, such as Tufted Grass (*Holcus lanatus*) and Common Groundsel (*Senecio vulgaris*), preferred 20 cm substrates. In the same study, species, such as Creeping Bentgrass (*Agrostis stolonifera*) and Broad-leaved Willowherb (*Epilobium montanum*), had no significant difference in abundance across the two substrate depths. Similarly, Madre et al. (2014) studied 115 sites in northern France, finding that some plant species, such as Couch Grass (*Elytrigia repens*) and English Plantain (*Plantago lanceolata*), grew on green roofs with deep substrates, while e.g. Sticky Mouse-ear (*Cerastium glomeratum*) grew on thin substrates. These studies partly confirmed the prediction by Brenneisen (2006) that the variety of substrate depth can result in a more diverse flora.

3.1.2 Plant Selection and Greening Methods for Green Roofs

Most of the searched empirical studies on biodiversity roofs were related to plant diversity, perhaps because a diverse plant community could provide fauna with different habitats for feeding and breeding (Thuring & Dunnett 2014).

Suitable Plants. Many plant species from different genera were examined in the reviewed papers, and the results showed that species selection influences the overall plant survival on roofs. Succulent plants, especially *Sedum* species, has been popular worldwide in the ground layer vegetation of green roofs (e.g. Bates et al. 2013, Lundholm et al. 2014, Lu et al. 2015) due to their high water use efficiency (Thuring & Dunnett 2014). Sedums were also found to have the most consistent cover either as dominant species or groundcover under other plants like grasses and to require little management (Thuring & Dunnett 2014).

Some studies suggested that native species should be favoured on roofs. For instance, some shrub plants, such as Strawberry Tree (*Arbutus unedo*), could suit green roofs under arid Mediterranean climate conditions (Raimondo et al. 2015). Van Mechelen et al. (2014b) suggested that plant species naturally occurring in Mediterranean open habitats, like Mountain Germander (*Teucrium montanum*), could be a good option on green roofs in Southern France. Olly et al. (2011) detected 29 non-seeded native species, e.g. Black Medick (*Medicago lupulina*), in their experimental roofs. Native species of protected status in France, such as Loose-flowered Orchid (*Orchis laxiflora*), were even recorded on local green roofs (Madre et al. 2014). In Taiwan, costal plants, such as Little Glory (*Evolvulus alsinoides*), were recommended to be applied on local green roofs (Chen et al. 2015).

Yet not all native species are suitable for green roofs. Some native species may perform poorly on roofs. For example, a study in Canada showed that while dryland species, such as Poverty Oatgrass (*Danthonia spicata*), had a good survival on roofs, wetland species, such as Deer Grass (*Scirpus cespitosus*), performed poorly (MacIvor et al. 2011). This was because the studied roofs resemble drylands more than wetlands. Furthermore, although native species avoid problems, such as biological invasion, slowly growing species are not good options to achieve “instant greening” (Butler et al. 2012, Raimondo et al. 2015). Green roof engineers tended to use non-native plant species to achieve fast greening (Bulter et al. 2012).

The life span of plants also impacts the performance of plants on green roofs, as annual species and perennial species complete their life cycle during different periods of a year (Emilsson 2008). Bates et al. (2015a) reported that perennial species, such as Rough Hawkbit (*Leontodon hispidus*), needed longer time to thrive than annual plant species, such as Cornflower (*Centaurea cyanus*); annual species usually functioned well in the first year after green roof installation but decreased in the following years. Bates et al. (2015 a) however noted that although the population of annual species decreased, their existence contributed to the species richness of roofs in the subsequent years of green roof installation.

The ability of plants to repel unwanted woody species was found to be vital to roof stability. Woody plants were considered to have potentials to harm green roofs, although their seedlings on roofs died when they were a few centimetres tall and no damage was detected on green roofs (Bates et al. 2013). Miller et al. (2014) tested 14 native plant species in Canada, e.g. Common Sedge (*Carex nigra*), on green roofs to repel two woody species, White Spruce (*Picea glauca*) and Scots Elm (*Ulmus glabra*). Their study showed that some plants, such as Red Fescue (*Festuca rubra*), repelled their woody competitors, but this capability varied from species to species.

Plant species combination is vital for optimising the performance of vegetation itself on green roofs, as plants may facilitate one another within their community by e.g. providing shade (MacIvor et al. 2011). For instance, MacIver et al. (2011) found that dryland species, such as Poverty Oatgrass (*Danthonia spicata*), were able to facilitate the performance of wetland species that did not originally manage on roofs, such as Large Cranberry (*Vaccinium macrocarpon*), meaning that facilitation between plant species could provide a wider range of species options for green roofs (MacIvor et al. 2011).

However, floral diversity per se is no guarantee of optimal results of green roof ecosystem functions, such as water capture and aboveground biomass (Lundholm et al. 2010). Emilsson (2008) found out that although mosses collected water, some moss species, such as Redshank (*Ceratodon purpureus*), became dry between rains events and hindered the green roof colonisation of vascular plants. Some mixtures of both wetland species and dryland species were reported to impair roof conditions, as they resulted in higher roof temperature and lower water capture compared to the mixtures of only dryland species (MacIvor et al. 2011). Also Lundholm et al. (2014) observed that some plant species, e.g. Bluebell (*Campanula rotundifolia*), grew better in a monoculture than in a mixture with other plant species

Current Methods for Vegetation Establishment. Current methods for roof greening are seeding, installing pre-grown vegetation mats, and planting succulent shoots or plug plants (c.f. Emilsson 2008, Olly et al. 2011), which have their own advantages and disadvantages. In the literature, seeding was regarded as an easy way to install vegetation, but it usually took a year or two before vegetation had fully grown and could be studied in details (Jones 2002). Molineux et al. (2014) discussed that especially commercial green roofs might be misjudged as failures if it took a long time for vegetation to thrive. Installing pre-grown vegetation mats thus were considered as an instant greening method (Emilsson 2008). The dense cover of vegetation mats, however, reduces chances for other species to colonise green roofs (Emilsson & Rolf 2005, Emilsson 2008). Planting shoots and plug plants is another way to achieve fast greening. It can bring “extra plant diversity” onto roofs, as plug plants are normally associated with weeds (Emilsson 2008). Planting plug plants, however, is more laborious than installing mats (Emilsson 2008). There is no perfect greening method for biodiversity roofs yet.

3.1.3 Fauna on Green Roofs

There is strong evidence that green roofs support fauna in cities. Invertebrates were the most frequently reported taxa in the reviewed studies. For example, Araneae (spiders), Hemiptera (true bugs), Coleoptera (beetles), and Gastropoda (snails) were reported to colonise green roofs in London, the U.K. (Jones 2002, Kadas 2006). Pollinators, such as bees and butterflies, were also common visitors on green roofs (e.g. Tonietto et al. 2011). Kadas (2006) reported that even some rare insect species were also collected on green roofs, e.g. *Microlestes minutus* (Coleoptera), of which there had been only six records in the U.K. in total. Furthermore, the density of collembolan in green roof substrates was found to be within the range at the ground level, perhaps due to the lack of predators, such as earthworms (Schrader & Böning 2006). Braaker et al. (2014) found that green roofs also acted as "corridors" or "stepping stones" to improve green space connectivity and diversified arthropod communities in urban areas.

Large animals can also benefit from green roofs. Biodiversity roofs were created as feeding habitats in the U.K. for e.g. black restart (*Phoenicurus ochruros*) that feeds on invertebrates (Gedge 2003). Pearce and Walters (2012) reported that bats sought prey on green roofs and that their visits on biodiversity roofs were significantly more frequent than on bare roofs. Some ground-nesting birds, such as Little Ringed Plover (*Charadrius dubius*) and Northern Lapwing (*Vanellus vanellus*), bred on flat green roofs, although no fledged chicks had been recorded yet (Baumann 2006). According to Baumann (2006), in Switzerland, a roof with only a gravel pit had four birds breeding successfully in both 2005 and 2006.

Floral diversity was found to be crucial to the overall faunal diversity of green roofs. Madre et al. (2013) observed that a diverse plant community diversified arthropod communities on green roofs. Also, Tonietto et al. (2011) found that the diversity of flowering plants was positively correlated with bee species diversity on green roofs.

Green roof age also impacts faunal diversity. Schrader and Böning (2006) reported that the diversity of collembolan at species level was significantly higher on old green roofs (8-12 years after installation) than on young ones (3-4 years after installation). In their study, collembolan species, such as *Folsomides parvulus*, appeared to prefer old roofs, and almost all *Mesaphorura krausbaueri* were found on old roofs.

Although green roofs do support faunal diversity, the species richness and the abundance of invertebrates on roofs were found to be lower than at the ground level (e.g. Colla et al. 2009, MacIvor & Lundholm 2011, Ksiazek et al. 2012). Furthermore, green roofs might protect fewer native species compared with parks, and they could not completely replace other green space (Tonietto et al. 2011).

Although supporting fauna was regarded as one of the missions of biodiversity roofs, some researchers claimed that animals might harm green roofs. For example, food-searching birds were found to pull out the moss layer, which damaged vegetation and reduced the attractiveness of green roofs (Emilsson & Rolf 2005, Emilsson 2008). Yet no other problems caused by fauna were reported in the reviewed papers.

3.1.4 Fungi and Bacteria on Green Roofs

Microbes were detected to colonised green roofs and have drawn green roof researchers' attention in recent years. Molineux et al. (2015) demonstrated that the green roof in London Zoo, the U.K., maintained more diverse microbial communities than brownfields. Also, McGuire et al. (2013) found that even small vegetated patches on green roofs supported a considerable fungal diversity and that green roofs served a similar ecological function for soil fungi to urban parks. McGuire et al. (2013) also discovered that the most abundant fungal taxa on the studied green roofs, e.g. *Pseudallescheria fimeti*, were closely related to taxa in disturbed urban soils and resistant to some contaminants.

Microbes in green roof substrates associated with plants but not always. John et al. (2014) studied the relationship between two fungal taxa and four plant species on green roofs. They found that dark septate endophyte colonised all the four studied species, Goldmoss Stonecrop (*Sedum acre*), White Goldenrod (*Solidago bicolor*), Poverty Oatgrass (*Danthonia spicata*), and Canada Bluegrass (*Poa compressa*), but arbuscular mycorrhizal fungi did not colonise *S. acre*. Arbuscular mycorrhizal fungi were also reported to have significantly more vesicle formation in *S. bicolor* (35.8%) than in *D. spicata* (20.5%; John et al. 2014). Yet McGuire et al. (2013) found no differences in the fungal communities across two different native plant communities, possibly due to the short time since planting (around one year) or the two plant communities having a similar chemical constitution.

Microbial communities were impacted by green roof substrates. For instance, only scarce arbuscular mycorrhizal fungi colonisation was detected in fresh growing substrates (John et al. 2014). Brick-based substrates appeared to support more bacterial biomass than concrete-based substrates; bacterial biomass tended to increase in shallower substrates (5.5 cm) over time, while fungal biomass seemed to increase in deeper substrates (8 cm; Molineux et al. 2014).

3.1.5 Current Management Practices of Green Roofs

The reviewed studies reported mostly low maintenance of green roofs, although some papers did not describe any management (see Appendix 2). The management mentioned in the reviewed papers mainly included irrigation, weeding, and substrate management.

Irrigation was a staple management practice in the reviewed studies. The intensity of irrigation depended on the demand of additional water supply of different species (Bates et al. 2015, Dvorak & Volder 2013). A study in Australia showed that Creeping Boobialla (*Myoporum parvifolium*) and Pig Face (*Carpobrotus rossil*) could use stormwater as a source during two-third time of a year, while

Flax Lily (*Dianella caerulea*) and Basket Grass (*Lomandra longifolia*) required additional irrigation throughout a whole year (Razzaghmanesh et al. 2014). Yet no study was specifically about irrigation on green roofs.

Weeding was applied on green roofs to keep biodiversity. Alien species and/or weeds were the main targets (Dunnett et al. 2008a, Nektarios et al. 2015), as competitive species might occupy living space from wanted species (Madre et al. 2014). Woody plant seedlings were also unwanted due to the potential damage that they may cause to roofs (Emilsson & Rolf 2005, Miller et al. 2014).

The reviewed studies showed that green roof substrates underwent changes. First, substrate depth tended to decrease over time, but the cause and when it happened remain unclear (Thuring & Dunnett 2014). Second, nutrients in substrates could be washed off by precipitation through leaching (Emilsson 2008), and some researchers used organic fertilisers to realise controlled fertilisation on green roofs, as organic fertilisers release nutrients slowly (Butler & Orians 2009, Cao et al 2014). Third, dead biomass tended to accumulate and influence floral diversity on roofs negatively (Thuring & Dunnett 2014). This is in accordance with the finding of Benvenuti (2014) who found that dead biomass hindered vegetation growth. Thuring and Dunnett (2014) thought the phenomenon was caused by an inadequate microbial activity due to a decreasing substrate pH. Schrader and Böning (2006) however found that old roofs, although having lower pH, had higher dehydrogenase activities than on young roofs. Emilsson (2008) proposed that the obstruction of microbial activities might have resulted from a lack of microbes in substrates, as substrates were heated to avoid weeds. In addition, organic matter itself had a decreasing decomposition rate over time, resulting in little nutrient releasing (Emilsson 2008).

3.1.6 Current People's Attitudes towards Green Roofs

Studies about people's attitudes to and preferences for green roofs showed that people were generally supportive to green roofs (Snep et al. 2009, Fernandez-Cañero et al. 2013, Jungels et al. 2013, Lee et al. 2014, Loder 2014, White & Gatersleben 2011). Two papers on people's perception of green roofs showed that people were willing to use green roofs (Yuen & Wong 2005, Rahman et al. 2015).

People in the reviewed studies generally had positive attitudes towards green roofs. An on-site study in the United States showed that respondents had somewhat high mean values of attitude towards green roofs (mean 3.90 on a scale 1 – 5) (Jungels et al. 2013). A study in Spain with digital images showed that all types of green roofs were scored significantly higher (mean >2.07 on a scale 1 – 5) than gravel roofs (mean 1.62) (Fernandez-Cañero et al. 2013). Lee et al. (2014) used synthesised images in their study and reported that the respondents rated all green roofs (mean 6.44 on a scale from 1 – 10) higher than the concrete bare roofs (mean 1.00). Snep et al. (2009) designed 6 different scenarios in a business site, finding that green roof scenario ranked the third place of all the other.

People were generally willing to visit green roofs. Yuen and Wong (2005) interviewed 333 residents at their homes in Singapore. They reported that the awareness of the roof gardens was high (90%) and that 84% of the participants were willing to use them, although only 18% actually did. Rahman et al. (2015) surveyed 104 respondents in a shopping mall in Malaysia and found that 47% of the respondents went to the mall for both shopping and visiting the roof garden. They also showed that 28% of the respondents went to the mall only to visit the roof garden. The respondents' reasons for visiting the roof garden in this survey were the beauty of the roof garden (25%), its restorative function (28%), the feeling of close to nature (27%), and the environmental learning(16%).

Although the residents seemed to like green roofs in the reviewed studies, entrepreneurs were shown to be a difficult group to cooperate with, as regards biodiversity roofs. A study by Snep et al. (2009) showed that entrepreneurs were unwilling to invest on green roofs, as they were usually up to £100 (c. €140) per m^2. Snep et al. (2009) also found out that enhancing biodiversity at business sites (including green roofs) was acceptable only if associated with good-looking appearance and tidiness, as well as cultural ecosystem services, such as recreation. Also, Snep et al. (2009) pointed out that green roofs with high biodiversity often had no lush appearance, which could be a challenge for the spread of biodiversity roofs.

People's preferences for different types of green roofs were found to be complex. For instance, biodiversity roofs might not always be attractive although they are liked. An image study in the U.K. showed that, of all the six roof types, the biodiversity roofs (brown roofs) had higher mean ratings of preference (>3.54 on a scale 1 – 7), affective quality (4.34), beauty (3.25), and restoration (3.75) than the non-vegetated roofs (means: 3.43, 4.17, 3.15, and 3.32, respectively; White & Gatersleben 2011). However, the biodiversity roofs gained the lowest mean rating (2.71 on a scale 1 – 5) of the statement "I would like to live there", compared with the Ivy green walls (4.00), the turf roofs (3.50), the non-vegetated roofs (3.39), the meadow roofs (3.11), and the sedum roofs (2.75; White & Gatersleben 2011).

Plant diversity seemed to impact people's preferences for green roofs. Lee et al. (2014) investigated 274 office workers who rated 40 different images of green roofs and one image of a concrete roof. They found that the preference of their respondents for a green roof was associated with the vegetation characteristics, such as height, colour, and flowering; more mixed plant features, however, were no guarantee to gain a higher preference score than roofs with less mixed features.

Finally, people's attitudes towards and perceptions of green roofs were found to be influenced by management of green roofs and people's socio-demographic background. Loder (2014) found that green roofs with a prairie aesthetic were regarded as messy and too wild looking and lack of maintenance in her on-site study. Fernandez-Cañero et al. (2013) reported that people's preferences were influenced by their childhood environmental background. Also, Lee et al. (2014) found that people with a stronger connection to nature understood the ecological function of green roofs better than those who were more departed from nature.

3.2 Results of the Interviews

This section presents the results of the interviews based on the thematic categories that arose from both the interview data and the literature review themes (See Methods section 2.2). I named these categories as 1) substrates, 2) possible "model ecosystems" and flora, 3) fauna, 4) microbes, 5) structural characteristics of roofs, 6) management to support biodiversity roofs. I also found that the interviewees had their own concerns about green roofs, and thus the concerns formed the seventh (7) theme.

3.2.1 Substrates

Substrate Materials. The interviewees mentioned a wide range of natural and artificial substrate materials that they thought could be used on biodiversity roofs. Most of the mentioned materials were natural, e.g. natural soils, sand, organic litter, and turf. However, it was also mentioned that materials like mineral soils might not be ideal due to their heavy weight. Peat was suggested as a good option for green roofs due to its high water holding capacity and light weight, but one respondent also noted that peat is combustible. Limestone was frequently mentioned, since some rare plant species, such as Birdeye Primrose (*Primula farinosa*), are inclined to alkaline soils. The moss expert who actually did experiments on green roofs said that ash worked poorly on moss green roofs.

Artificial materials were also mentioned as good green roof substrates. The vascular plant expert specified mineral Leca®, a kind of round clay grains that can absorb and keep moisture. He said, *"It eliminates moisture loss all the time, so it's an ideal material. And it's light."* Mulch was also mentioned as material that could be used to conserve moisture, and it could also reduce the weed cover. Furthermore, the moss expert advised using cloth and fabric as substrates for mosses. He reckoned that thin substrates are enough for mosses, and that cloth and fabric can keep moisture longer than many other materials, such as sand.

Specifically for biodiversity roofs, many of the participants suggested using mixtures of different materials, as different flora and fauna favour different types of substrates. *"Our highest native biodiversity in Finland is in the areas where we got various soils"* (vascular plant expert).

Substrate Characteristics. The experts thought that the most important characteristics that the substrate should have low bulk density and be well drained for the safety of roofs, while the ability to keep the moisture of the substrates was also wanted to buffer against drought. The participants discussed substrate pH, particle size, nutrient content, and organic matter content, and they also further explained how these characteristics could influence roof biodiversity (Table 2).

Table 2 The interviewees' opinion on substrate characteristics and their impacts. See text below for the more detailed explanation.

Substrate characteristics	The impact(s) of the characteristics
Substrate pH	1. Different flora and fauna prefer different pH.
Particle size	1. In the Finnish context, small-sized particles are preferred due to the high water holding capacity.
Nutrient content	1. Poor-nutrient substrates favour dry meadow species and prevent surface water contamination. 2. Special nutrients, e.g. calcium, support rare species.
Organic matter (OM) content	1. OM supports water supply by keeping moisture. 2. Substrate depth decreases fast if OM content is high.
Substrate depth	1. Roof weight increases with substrate depth. 2. Different flora and fauna prefer different depth. 3. Substrate depth is negatively correlated with substrate temperature variation.

Substrate pH was thought to impact what kind of flora and fauna could thrive on biodiversity roofs. For instance, the moss expert said that most mosses favoured pH lower than 5.5, while limestone moss species required higher pH than 5.5. The pollinator expert thought that substrate pH might not influence pollinator nesting much in general, but some special species are found in limestone habitats. He said, *"It [a roof substrate that includes limestone] might be more suitable for* *some [pollinator] species, but those species are extremely rare in Finland."* The microbe expert reckoned that substrate pH could be around 7 so that both plants and soil microbes are able to adapt to the roof ecosystem. The sunny habitat expert suggested having various pH in different parts of a biodiversity roof to benefit different species. To create different pH, *"You can simply use rock material, which is either acidic or neutral or with higher pH,"* said the expert.

As for particle size of substrates, the moss expert answered *"the smaller ones, well, as small as possible, is good"*, mainly concerning the impacts of soil moisture on the survival of flora and fauna on green roofs. The pollinator expert thought particle size should be near to sand so that some pollinators are able to dig nests in holes. *"If it's too tight, like clay,"* said the expert, *"it's not possible to use for nesting."*

Half of the participants talked about nutrient content in the substrates of biodiversity roofs. They mainly thought that the substrates should be unfertile, *"because species living in dry meadows prefer nutrient-poor soil and many rare pollinator species build nests in sandy soil but not in clay or nutrient rich soil"* (pollinator expert). The moss expert said that mosses need no fertilisers, as they take nutrients from rainwater instead of substrates. Two interviewees pointed out that fertilisers could be utilised on biodiversity roofs, but there are possible good and bad effects: nutrients may benefit plant growth, but they can be washed away by rain, which contaminates water and aggravates urban environmental problems.

Although the substrates of biodiversity roofs should have a low level of nutrients, the sunny habitat expert highlighted the importance of calcium, an essential nutrient for plants. The expert said, *"In grassland particular, if you have calcium there, you could then find very special plant species. That would be the same on these roofs. You have some suitable sorts of calcium for these plants, and that would help you to improve the chances of getting rare plant species growing on them."* He also suggested that a gradient of nutrient contents could be applied on biodiversity roofs so that different species establish themselves in different areas that are suitable for them.

Organic matter content should be moderate, somewhere around 10%, according to two respondents, as they explained that substrate depth might decrease faster if the organic matter content at the starting point was too high. Another participant considered that organic matter had a high moisture level, which is a burden for the roof as moist organic matter can be heavy. He suggested having various contents of organic matter in different parts of a green roof to divide the burden more evenly. The various contents of organic matter could also contribute to the overall heterogeneity of the roof as well.

Most of the participants considered that substrate depth could be determined by the requirement of target species. For some plants, e.g. mosses, a thin substrate layer is enough, while herbaceous plants and shrubs need deeper soil, and trees might require even much thicker substrates. Moreover, different soil fauna, such as insects and earthworms, also need different substrate depths. The pollinator expert suggested that substrate depth should be more than 10 cm, in order that pollinators are able to dig nests to the substrates of green roofs.

Substrate temperature variation was considered as a challenge for soil microbes. According to the microbe expert, thick substrates have less soil temperature variations compared to thin substrates. However, one respondent underlined *"it's not the case that the thicker the substrate is, the better it is"*, as a thick substrate also means a lot of weight, which is a burden to roofs. Some respondents hence suggested having a combination of different depths to support roof biodiversity.

3.2.2 Model Ecosystems and Flora

Possible "Model Ecosystems" in Finland. Openness, dry and sunny were the main mentioned features that a "model ecosystem" for biodiversity roofs in Finland should have. The most frequently mentioned model ecosystems were meadows, more specifically dry meadows that were mentioned by half of the experts. According to the interviewees, mimicking dry meadows could increase the conservation value of biodiversity roofs, as dry meadows have become scarce in Finland due to land use change, especially agricultural practices. The experts explained that meadows could provide habitats for flowering plants, even endangered species, such as *Thymus* spp., that are attractive to insects. A mentioned ideal habitat similar to dry meadows was esker ridges, a type of gravelly exposed habitats formed in the glaciations and often surrounded by forests. Esker ridges can also support *Thymus* spp.

Rocky outcrops and open cliffs were also considered as possible model ecosystems, since they are dry, sunny habitats and common in Finland. The vascular plant expert pointed out that sandy seashore habitats could be ideal ecosystems too, as they are environments with sandy soil and usually located in sunny position. *"They are rare ecosystems (in Finland) but still exist"*.

The soil expert reckoned that a lichen-based community was worth mimicking, as lichens can thrive on shallow soils and bare rocks. However, he pointed out that habitats with only lichens cannot support insects, and flowering plants thus are still needed to support biodiversity on green roofs.

The bird expert thought that archipelagos were ideal environments for birds, and thus could be mimicked on roofs. According to him, the open islands are natural breeding sites for birds, such as gulls (family Laridae). He said, *"I would see, perhaps, green roofs like islands in the ocean of the other human activities, so it could kind of work in that way as well"*. By openness, he meant a habitat with limited vegetation height instead of bare sand or rock habitats.

Suitable Plants and Unwanted Plants. According to the experts, suitable plants for biodiversity roofs can be species that naturally occur in the model ecosystems mentioned above. Half of the respondents delineated characteristics that plants should have to survive on roofs and even listed specific species. Some respondents also provided opinions concerning vegetation and climate change.

Blackland thyme (*Thymus serpyllum*), a rare species in Finland, was frequently mentioned because it supports a wide range of insects. Other plant species mentioned was Oregano (*Origanum vulgare*) that is favoured by pollinators, owing to its nectar rich in sugar. Bellflower (*Campanula* spp.) and Antennaria (*Antennaria* spp.) were also recommended, as they are attractive to insects, and even many bee species specialise on them. Also, some pollinators, e.g. the Chequered Blue Butterfly (*Scolitantides orion*), specialise on *Sedum* species. The vascular plant expert pointed out that *Sedum* spp. are representative succulents that could be an ideal plant species for green roofs since they are tolerant to dryness thanks to their thick leaves and high water content.

Other mentioned species that naturally occur in dry, open habitats and thus could be suitable for roofs were Heartsease (*Viola tricolor*), Yellow Bedstraw (*Galium verum*), Maiden Pink (*Dianthus deltoides*), and Sand Pink (*Dianthus arenarius*). *V. tricolor* grows on rocks, while the other three grow on dry thin soils. Dandelion (*Taraxacum* spp.), a common native weed in gardens, was also mentioned as a possible species for biodiversity roofs. Yet the moss expert pointed out that dandelions could be used only if they do not harm the vegetation, since they may occupy a whole roof.

The moss expert highlighted that a green roof with only mosses was unlikely to be a biodiversity roof due to its limited attraction to insects. He, however, continued that sedges and dwarf shrubs that usually grow in natural mossy environments could be planted on moss roofs to increase biodiversity, as dwarf shrubs in mossy swamps have small beautiful flowers that are attractive to pollinators. Another expert considered that dwarf bushes with berries may also support birds.

Although grasses were mentioned as possible plants for biodiversity roofs, it is still debatable what sorts of grasses suit biodiversity roofs. The soil expert thought that grasses together with low vascular plants or creeping vascular plants were worth trying since they are easy to maintain. He continued that grasses might require a large amount of water that will increase the roof weight. The vascular plant expert was also concerned about water issues. He reckoned that tall grass species were unsuitable for roofs, as they cannot tolerate drought if water conditions are not arranged well on roofs.

According to some of the respondents, rising temperature and climate change in Finland should be taken into account when selecting plants on biodiversity roofs. They suggested introducing species into Finland from southern countries, such as Baltic countries and Central Europe, as these species have adapted to higher temperatures. Yet the experts warned that one should beware of invasive alien species that the assisted introduction of species might bring along. The vascular plant expert proposed to introduce **the same species** that already exist in Finland. The moss expert also suggested planting species native to southern Finland onto the roofs located in northern parts of the country.

Plant Characteristics That Support Biodiversity. To support biodiversity on green roofs, all participants mentioned the importance of morphology, i.e. that form and structure of vegetation should be suitable for roofs. Some experts emphasised that a long flowering season was vital to fauna dependent on flowers. The two plant experts and the pollinator expert pointed out that flowers with different colours and shapes could attract different insects. In addition, many interviewees highlighted that a mixture of plant species could prevent pests better than a monocultural vegetation. Hence, as the pollinator expert expressed, *"it would be good to have many different flowers"*, to support different insects at different times of a year and to avoid the prosperity of only one species.

Carabids, spiders, and birds could also benefit from plant diversity. According to the carabid expert, carabids can be generally divided into two groups: granivorous (seeds-eating) and predator carabids. A diversity of plants can ensure food availability for both seeds-eating carabids and predator carabids, by providing seeds and attracting insects respectively. Also, spiders and insectivorous birds can benefit from a diversity of plants for the same reason as predator carabids.

Furthermore, vegetation may provide nesting sites for spiders and hiding places for birds. According to the spider expert, different spider species prefer different vegetation structure but have no inclination for any specific plant species. Spiders that build small webs prefer closed branches, while spiders that build large webs favour open branches. "*It doesn't really matter if [it is] this [plant] species. It can be replaced by something similar in terms of structures of the plant"* (spider expert). According to the bird expert, for some birds, such as the Northern Wheatear (*Oenanthe oenanthe*), the vegetation height can be crucial. A common situation mentioned by the expert was that migratory birds wintering in Africa, for example, arrive at the breeding grounds in early spring when the vegetation has not fully grown. In summer, *"they become really high vegetation, which is not optimal for their [birds'] breeding areas,"* as the bird expert expressed.

Establishing Green on Roofs. Unlike natural habitats, biodiversity roofs may lack seed bank at the starting point, and need to establish vegetation artificially. Most of the interviewees talked about how to establish vascular plants, but only the moss expert delineated details for mosses. For vascular plants, three methods were brought up by the participants: sowing seeds, spreading mats, and transplanting. Sowing was the most frequently suggested method, although it was also considered as the slowest method. A respondent advised sowing mixtures of 10 to 15 dry meadow species into the roof substrates. He said, *"You could strike there, and you have heterogeneity there. The balance would change over the first year or two. And you would get most specialised species established the place where are suitable conditions for them, like some calcium in one area, or rock, things like that."* Also, another participant regarded sowing seed mixture as the easiest way since it suits plant species with big roots, such as *Thymus* spp.

Establishing pre-grown vegetation mats was considered as the fastest way to green a roof. Turfs have already been commercially produced, as an interviewee noted. Yet turfs alone might not support biodiversity, as they are made of only grasses. The respondents mentioned that other species, such as *Thymus serpyllum* and *Sedum* spp., could be produced as mats too. A tip from the vascular plant expert was that the soil attached to plant roots ought to be taken to roofs simultaneously with establishing plant mats.

For those plants that cannot produce mats, transplanting was suggested as a solution. The participants thought that plants could be first grown in cultivation and then transplanted onto roofs. For succulent plants that reproduce by vegetative propagation, their cuttings could be spread onto roofs. Plants that undergo sexual propagation could be transplanted as small plug individuals.

Similar to vascular plants, mosses can be directly brought to a roof as a mat, but it should be covered with net or cloth to protect mosses from birds and excessive sun. Another mentioned way applicable to middle and big-sized roofs was that mosses are ground into powder and spread onto the substrates. The new growth will emerge from these small fragments later.

3.2.3 Supporting Animals on Biodiversity Roofs

According to the respondents, biodiversity roofs in Finland can support fauna that has access to roofs, but not much e.g. minks, foxes, snakes, rabbits, or mice. Insects, especially pollinators, were the most frequently mentioned group in the interviews. Carabids were also mentioned, as predator carabids mainly eat worms, snails, and caterpillars, and they could protect vegetation from overabundant pests. The spider expert said that as long as there were insects, spiders that are able to parachute would appear on roofs. This is because almost all spiders in Finland are generalists. Birds were frequently mentioned as potential biodiversity roof visitors too. According to the interviewees, some birds, such as seagulls (family Laridae) and waders, tend to build nests on all kinds of roofs, no matter if they are green or not. Yet one respondent said, *"Perhaps the vegetation will increase the willingness of birds to breed on the roof."* Some gull species may benefit from biodiversity roofs by using vegetation as shelters from wind or predation of nestlings. The bird expert specified that especially the Northern

Wheatear (*Oenanthe oenanthe*), a passerine species, might benefit from biodiversity roofs, as it feeds on invertebrates and breeds in cavities in open habitats.

To support fauna on biodiversity roofs, the respondents suggested using extra elements to support different taxa by providing food and nesting sites (Table 3). To create diverse habitats for insects, the experts suggested providing substrate depth heterogeneity, rocks, stones, as well as deadwood that is an indicator of biodiversity in boreal forests. The pollinator expert suggested that blocks or logs with holes, reeds, and other plant stems might increase the number of pollinators on roofs by providing nesting sites. A respondent recommended using insect hotels that have already become popular in parks. Yet it is unrealistic to bring their actual nesting reeds or wooden blocks to green roofs to enhance roof biodiversity.

Table 3 Elements that the interviewees suggested to support fauna on roofs.

Target taxa	Interviewees' opinions on how to support specific taxa
Insects	1. A diversity of plants species is needed. 2. Rocks, stones, deadwood, blocks or logs with holes, reeds, other plant stems, and insect hotels can provide nesting sites. 3. Substrate depth heterogeneity is needed.
Spiders	1. Sandy soil may attract the rare species in Finland. 2. One-metre-high bushes can support web building. 3. Disturbance in the substrates, e.g. constant trampling, should be avoided.
Birds	1. High places formed with a pile of rocks or sticks on green roofs for birds to scan predators. 2. Vegetation should be kept short. 3. Hollow rocks can support cavity nesting birds.

A diversity of plants was regarded as an indirect factor impacting spiders, as many spiders feed on insects dependent on plants. The spider expert reckoned that sandy habitats with suitable plants might attract the rarest spiders in Finland. He considered that approximately one-metre-high bushes could provide an ideal structure for web building, but trees might be unnecessary on roofs since more than 80% of Finland is covered with forests. Furthermore, some places on roofs should be left without intervention, e.g. constant trampling, to avoid disturbance on substrates where many spiders and insects live.

To support birds, the bird expert advised creating high places on roofs, e.g. piles of rocks or sticks, so that birds can scan predators. The bird expert pointed out that invertebrates should be available on roofs to support e.g. Northern Wheatears, and that grasses should be kept short since Northern Wheatears prefer short vegetation. Hollow rocks can be placed on roofs to mimic nesting cavities for cavity nesting birds like Northern Wheatears. The bird expert considered that woodland bird species could breed on roofs if trees were available; however, *"probably, in that case, it wouldn't be that much so endangered or they don't have such high conservation status than wheatear or some gull species"*.

Many experts reckoned that climate change has already influenced fauna. For instance, some butterfly species are shifting their range northwards, e.g. from Baltic countries and Russia into southern Finland. However, one expert doubted if roofs could support these species as they might be restricted to cold habitats, while roofs are in general hot environments. Moreover, some of the interviewees thought it was unnecessary to consider climate change on biodiversity roofs because climate change is a long process and other factors, such as land use changes, have more impacts on fauna than climate change.

Although biodiversity roofs aim at supporting biodiversity, supporting animals might cause problems to roofs themselves. Blackbird (*Turdus merula*), for example, was highlighted by some participants. Blackbird is a common bird species e.g. in Helsinki, Southern Finland. It throws away plants when digging soil for food, which might harm the roof vegetation. Other mentioned birds were seagulls and starlings that might bring too much bird droppings and thus influence people's attitudes. Furthermore, birds would influence the seed bank on biodiversity roofs unpredictably: Birds might bring seeds from elsewhere, but they might eat the existent seeds on biodiversity roofs as well.

3.2.4 Microbes, a Part of the Green Roof Ecosystem

Microbes. Many of the participants talked about the role that microbes play in the nutrient turnover, as well as symbiosis. The experts pointed out that some microbes are decomposers that release nutrients from organic matter into bioavailable forms (i.e. forms absorbable to plants). Some microbes are responsible for nitrogen fixation, a process in which atmospheric nitrogen (N_2) is converted into nitrogenous compounds absorbable to plants. Microbes associated with leguminous plants (family Fabacae) were frequently given as an example, as they enhance soil nutrient contents. The moss expert took blue-green bacteria (Cyanobacteria) as another instance: blue-green bacteria that thrive in moss carpets in forests take nitrogen directly from the air and fix it into bioavailable compounds that plants can use after blue-green bacteria die. Furthermore, the participants thought that microbes were beneficial to animals, such as some seed-eating carabids that use bacteria from soil to help digest seeds. Yet the microbe expert addressed that there was a lack of studies on the symbiotic relationship between plants and microbes in habitats like green roofs.

According to the respondents, unwanted microbes could be generally divided into two groups. One was wood decaying microbes, such as nematodes and wood decaying fungi, as they might decompose the wooden structures of buildings. The other group was pathogens: Plant pathogens might damage roof vegetation, while animal pathogens might cause diseases to animals, especially humans. The interviewees noted that biodiversity roofs were built to benefit not harm human well-being.

The Survival of Wanted Microbes on Green Roofs. According to the interviewees, the survival of microbes is determined by many factors. Moisture was the most frequently noted factor. First, soil moisture can determine whether the soil is fungi-dominated or bacteria-dominated. The soil expert gave an example that in peatlands, fungi are more active than bacteria. Second, some microbes, such as blue-green bacteria, favour moisture. *"If you have a shady,* *moist moss carpet that seems to be doing well, there will always be these blue-green bacteria, too"*, said the moss expert. Furthermore, another respondent pointed out that it took time after drought before microbes that survived over dry periods became active again. To avoid this situation, he suggested keeping a stable, low moisture in green roof substrates.

The temperature was often mentioned with moisture, as microbial activity is limited by temperatures. According to the microbe expert, temperatures in the substrates of green roofs might vary dramatically, especially in thin substrates, which is a huge challenge to the survival of microbes and other living organisms on biodiversity roofs. He suggested using deep substrates, as the temperature of a deeper substrate (e.g. 20 cm deep) does not fluctuate as tempestuously as thinner substrate (e.g. 3 cm deep).

Plant performance is also crucial to the survival of microbes that are associated with plants. The vascular plant expert and the microbe expert emphasised that symbiosis is in both ways: plants and microbes need each other. Living plants are essential to keep these microbes alive since e.g. some fungi are completely dependent on sugars produced by growing plants. Improving plant performance is a way to support microbes.

The nutrient condition of substrates and the use of chemicals also influence microbes. The experts pointed out that nutrient-poor soil was required by microbes associated with leguminous plants. *"If you already have soil, which is very rich in nutrients, especially nitrogen, then it's not possible to grow these plants, at least, very effectively"* (pollinator expert). The interviewees thought that chemicals, such as pesticides, can kill microbes, and are unnecessary on green roofs since pests are not a problem on green roofs in Finland at the moment.

Finally, besides most of the participants suggested special actions on how to help wanted microbes survive on biodiversity roofs, the carabid and sunny habitat expert gave a differing point of view. He said, *"Probably best not to think about* *it, but if we put it in habitats that are suitable for plant species adapt to this harsh conditions, then it's very likely that microbes that they normally interact with could be there anyway. And if there are not, they won't manage. ... Probably the best thing is just to assume that they would be there and they could manage or not manage according to resources there."*

3.2.5 Structural Characteristics of Roof

The main roof structural characteristics discussed in the interviews were roof size, height, slope and direction of slope, and location (Table 4), as well as other roof structures (Table 5).

Roof Size. The respondents thought roof size was important in terms of biodiversity. Most of the interviewees held the opinion that in principle, the larger a green roof was, the better organisms could survive. According to the experts, animals could move from unsuitable parts to other parts of the same roof to establish their population successfully if the roof is large, while small-sized roofs might support only limited plant species and thus attract a limited number of animals. In addition, a small green roof might even be a sink/trap habitat, especially when isolated from other green spaces such as parks. A participant, however, pointed out that large green roofs involve more work to be installed and managed.

Roof Height. According to the interviewees, roof height can influence the accessibility of fauna and propagation of flora to roofs, as different taxa have different accessibilities to roofs. Birds and spiders were considered to be able to easily access roofs in general since both taxa have good dispersal abilities, i.e. all birds can fly and approximately three-quarters of spiders in Finland are capable of ballooning. Although insects are less capable of coping with wind speed and wind direction during flight, some interviewees pointed out that in the Finnish context, insects could still access roofs, since most buildings in Finland are low, i.e. six- to seven-storeyed at highest. The pollinator expert suggested that, as there was not much knowledge yet, the dispersal of insects onto roofs under Finnish conditions should be studied in more details. As for plants, *"the higher a building is, the more difficult it is for native species to spread from a surface lower to a roof, which is, for example, at 60 metres height"* (vascular plant expert).

Table 4 Mentioned structural characteristics and other elements that affect biodiversity on green roofs.

Roof characteristics	Interviewees' opinions
Size	1. Large roofs support higher biodiversity than small ones. 2. Small roofs can be a sink/trap habitat, especially when isolated from other green spaces. 3. Large roofs require more work in installation and management. 4. Roof size is not vital, but there should be a scattering of the green roof distribution to achieve ecological effects.
Height	1. Roof height influences the roof accessibility and dispersal of flora and fauna. 2. Roof height has little influence on high-mobility fauna in Finland, as buildings are relatively low. 3. Roofs on top of high buildings are a refuge from urban distraction at the street level.
Slope and Direction	1. Roof slope determines if an existent roof can be converted into a green roof. Flat roofs are easy, and steep sloping roofs are impossible. 2. Roof slope determines if roof direction influences roof biodiversity. Sloping roofs have different microclimates in different faces, which support biodiversity. 3. Roof slope creates heterogeneity of water and nutrient content in green roof substrates, which contribute to biodiversity.
Location	1. Roof geographical location impacts sun exposure and the wind. 2. Roof location in the cityscape influences the connectivity between a biodiversity roof and other green spaces.

Interestingly, the bird expert brought up a relationship between roof height and disturbance to animals. He reckoned that some birds, such as gulls (family Laridae) and waders, might benefit from large roofs located on the top of high buildings, especially in densely built and congested urban areas. Besides a roof high up can function as a refuge from urban disturbance, birds could benefit from high locations, as their main predators (e.g. foxes) have no access to the roofs.

Roof Slope and Direction. According to the interviewees, roof slope may influence the possibility of converting existent bare roofs into biodiversity roofs, as well as substrate water and nutrient contents. According to the respondents, flat roofs are easy to establish green, while it is difficult to keep substrates on roofs with steep slopes. The interviewees noted that biodiversity roofs could be built on roofs with slight slopes. Some of the interviewees pointed out that flat roofs might suffer from water accumulation and thus have high risks to be flooded. A flooding roof might damage roof structures and harm biodiversity, e.g. destroying bird nests and nestlings. Furthermore, roof slopes could bring about heterogeneous substrate water and nutrient contents *"when water runs quickly down hills and nutrients go with it"* (carabid and sunny habitat expert). The gradients of water and nutrients could result in different and diverse vegetation.

Roof slope also determines how roof direction influences living organisms on green roofs. *"If you have a sloping roof for a gently sloping roof, then one might expect quite big differences, so certainly south- and southwest-facing slope would be warmer than north- and northeast-facing slope. Whether it is steep enough, the roofs, it would affect* ***A.*** *whether it can actually put a green roof on it, and* ***B.*** *they would actually affect the amount of temperatures and microclimate. They may and may not be a big issue"* (soil expert). Sloping roofs could provide different microclimates, as slopes facing different directions have different exposure to sunlight and the wind. Species thus could choose where to stay according to their preferences, e.g. some fauna and flora prefer sunlight, while others prefer shade, as well as situations, e.g. in Finland, cold might impact birds more than hotness, but *"if it gets too hot, they can get some shelter (from cool sides of sloping roofs)"* (bird expert). Furthermore, *"wind speeds may be particularly in relation to orientation of the building"* (soil expert), which could influence the presence of insects and the extent of soil erosion on green roofs.

Roof Location and Landscape. Roof geographical location was thought to be crucial due to its impact on sun exposure and wind. The microbe expert gave an example that a green roof near seashore might suffer from the wind that impacts the survival of plants and the presence of insects. Yet if there were high buildings around the roof, the effects of wind might diminish.

Although my study questions focused on the habitat and ecology within biodiversity roofs, the participants also talked about the importance of the surrounding landscape to biodiversity. According to them, biodiversity roofs should be connected with other green spaces at a landscape level. The microbe expert said, *"I think, in order to achieve ecological effects, there should be a scattering of green roofs, no matter what sizes they are"*. By connecting with other green roofs and green spaces, a biodiversity roof could also function as a "corridor" or stepping stone connecting separated wildlife populations. Furthermore, the heterogeneity of green roof types at a landscape level was emphasised: *"If we want to enhance biodiversity with green roofs, then we probably want to have many sorts of green roofs, not all the same sort"* (carabid and sunny habitat expert). The bird expert also recommended having a mosaic type of roof landscapes so that fauna that breeds on biodiversity roofs could seek different habitats to satisfy different needs.

Possible harmful structures. The participants thought that some roof structures might harm biodiversity on green roofs, but no factors were considered as "lethal" (Table 5). Heat emission on roofs was frequently discussed, as many organisms cannot tolerate heat and smoke. However, two respondents were optimistic. The spider expert thought fauna and flora might benefit from heat during winter in the Finnish context. The carabid and sunny habitat expert regarded heat emission as an opportunity to increase heterogeneity on roofs and explained, *"... you can have more species than if you own them just all the same because there are some species which require this kind of heat. ... It gonna give chance for those species that can tolerate that."*

Ventilation, a mechanical system exchanging the air of a building, was mentioned by the vascular plant expert. Ventilation involves more than heat emission, and the air current from a building can be too hot and/or too moist and is always present. However, he said, *"It's really a small area in the roof. So concerning the whole roof, I wouldn't think it's a problem."*

Table 5 Interviewees' opinions about possible structures on roofs that may influence roof biodiversity.

Mentioned structures	Interviewees' opinions
Heat emission	1. Heat emission can harm biodiversity roofs due to high temperatures and smoke. 2. Heat emission may help flora and fauna overwinter in the Finnish context. 3. Heat emission can create temperature heterogeneity on green roofs.
Ventilation	1. Ventilation involves both heat and moist emissions that harm living organisms on green roofs.
Some green roof layers	1. e.g. storage layer without water can damage or even kill plant roots.
Poisonous materials	1. Poisonous materials are lethal to living organisms on green roofs, but in reality, they are not allowed to be used.
Other structures	1. Electric powers, lifts, and e.g. transmission cables may influence, but the effect is still unknown.

Some layers of the green roof itself were regarded as fatal factors to plant roots by the microbe expert who currently did some experiments on green roofs. He said that storage layer without water could lead to a high temperature that damages plant roots and threatens the survival of plants. He thus suggested omitting unnecessary layers according to the local conditions.

Structures containing heavy metals and other poisonous substances were brought up as a possible "lethal issue" by the vascular plant expert. Poisonous substances could harm the survival of organisms on green roofs and *"what is bad for plants is also bad to human"*. The expert, however, regarded it as a theoretic risk, since *"dangerous materials are not allowed to be used where people live or stay"*.

A careful design was thought to be crucial before installing a green roof on an existent roof. A participant noted that electric powers that usually appear in a building, such as lifts and transmission cables, should be considered, although their effects were unknown. Structures that always shade a roof should be avoided due to the importance of sunlight to plants and pollinators.

3.2.6 Management for Biodiversity Roofs

All participants thought that management was necessary on biodiversity roofs since they are artificial environments and not as stable and resilient as natural ecosystems. The interviewees mainly discussed management of water, vegetation and substrates, and brought up some other possible management (Table 6).

Water Management. Water is vital for living things, but it also puts on roof weight and possibly leads to roof overload. Some of the participants thus thought it was impractical to store water underneath the substrate, and an interviewee considered it unnecessary, as he expressed that *"as long as soil is kept moist, then you might not need to have water retain underneath of it."* The carabid and sunny habitat expert thought that water should be drained away to avoid roof overload. The requirement for drainage systems was that *"the system gets it [water] away, but not too fast"* (the carabid and sunny habitat expert); otherwise, the habitat cannot benefit from water that hits the roof. The expert also regarded regular checking as a requisite to ensure that a drainage system works.

Irrigation was considered as a necessary management to support biodiversity. The microbe expert addressed the importance of irrigation in the first one or two years when a biodiversity roof is installed since it takes time for plants and microbes to adapt to roof environments. Afterwards, watering can be unnecessary during normal summers when rains are regular. The microbe expert thought that the idea of irrigation was to help vegetation and microbes manage themselves eventually, but irrigation should be carried out during exceptionally dry summers to avoid vegetation loss.

Table 6 Interviewees' opinions on necessary and unnecessary management.

Management	Further descriptions
Water management	1. Irrigation is needed in the first year of installation and during drought, but no specific irrigation timing was given. 2. Drip systems and sprinklers were suggested as possible ways for irrigation. 3. In the Finnish context, tap water can be directly used for irrigation, and collecting rainwater is an economic irrigating way. 4. A well-designed small pond can supply water to plants and attract semi-aquatic fauna, e.g. dragonflies, but a small pond may also damage roofs but be too small for spiders and birds.
Vegetation management	1. It is necessary to weed by mowing and manually pulling out competitive species and/or tree seedlings. 2. Intentional renewal of vegetation can be necessary on green roofs, since vegetation change over time.
Soil management	1. Fertilisation is necessary when vegetation performs poorly, but nitrogen should not be a problem in urban environments. 2. Removing superfluous organic matter (dead plant biomass and bird droppings) is necessary since it is an obstacle for plant growth.
Pest Control	1. Pest control might be unnecessary since biodiversity roofs attract both plant-feeding animals and predators, the latter of which protect plants from overgrazing.
Monitoring roof conditions	1. It is necessary to regularly check substrate moisture, vegetation performance, substrate pH, nutrient condition, organic matter content, drainage, and the physical structures of green roofs.

The interviewees, however, did not give answers to irrigation timing, and they suggested using automatic irrigation systems, as well as moisture monitoring systems if possible. According to the participants, drip systems and sprinklers could be ideal to mitigate the impact of dry summer that might appear more frequently than before in Finland due to climate change. Drip systems and sprinklers use a little water and do not damage vegetation. *"You cannot just take a bucket of water and water it. Then it [refers to vegetation] will be finished"* (the moss expert). The microbe expert inferred that irrigation should be carried out when plants looked withered. Some of the respondents suggested watering green roofs according to substrate moisture monitored by automatic systems that have been realised in some countries, such as Japan. Furthermore, in the Finnish context, tap water can be directly used for irrigation, as it contains little lime and does not kill plants that prefer acidity. To reduce the financial cost, some of the interviewees suggested collecting and using rainwater for irrigation.

The participants had two totally different opinions about small ponds for irrigation. The supporters believed that ponds on roofs could provide water supply to plants and attract semi-aquatic species, such as dragonflies, if well-designed; yet a regular roof checking is needed. The opponents thought small ponds were impractical and unnecessary due to their potential damage to roofs and limited support to animals, such as spiders and birds. According to the experts, spiders are territorial animals and eat each other if the pond is only one or two square metres large, and birds can fly a long distance for water.

Vegetation Management. Most of the participants thought that weeding could be needed on biodiversity roofs when strong competitors and/or tree seedlings established on roofs. Strong competitors can be invasive alien species or even native species that accommodate themselves to green roofs better than other wanted species, and thus may colonise the whole green roof and reduce roof biodiversity. To maintain biodiversity on green roofs, the dominant species should be mown or pulled out, just as the carabid and sunny habitat expert said *"nobody wants to involve a lot of work to go opposite of biodiversity. Then you go back to it two years later, there's just lupin and ... some other kinds of invasive plants. That could be a problem"*. Some of the interviewees supposed that tree seedlings should also be shunned, as the growth of trees could depress meadow species that prefer open landscape, and tree seedlings may damage the physical structure of a roof that is not explicitly planned for trees.

Unexpectedly, the vascular plant expert called attention to renewing vegetation intentionally, as green roof vegetation changes over time. He said, *"You have to renew the species composition on the green roof anyway at some point. ... most species have a certain life period. Some external factor will destroy some of the* *population. If the species are not able to spread onto the roof, then you have to bring new plant material there."* According to him, species reproducing with seeds require vegetation renewal on a shorter time scale than plants propagating through runners, especially when seed production is inadequate.

Soil Management. Fertilisation is necessary when vegetation performs poorly, as the vascular plant expert expressed, *"If the plants are not doing well, it may be also the question that there are some limitation of nutrients."* He advised checking nutrient conditions in substrates, especially when *"the organic layer is very thin. ... Nitrogen will appear by the air, but some other nutrients will probably not enough."* According to him, nitrogen is no problem in urban environments, because *"there are always humans producing nitrogen and it comes down by the rain."* The respondents reckoned that although dead biomass could release nutrients, fertiliser might be still demanded when inadequate amounts of nutrients were released from dead biomass.

Some respondents brought up removing superfluous organic matter that mainly consists of dead plants and bird droppings. The microbe expert noted that overmuch dead biomass could hinder plant growth. Yet one respondent did not regard dead plants as a problem, since *"mostly these roofs have such sparse vegetation and a small amount of growth that have no need to manage it."* Bird droppings, however, cannot be avoided if we aim at supporting birds. The accumulation of bird droppings on roofs will influence people's attitudes of supporting birds.

Pest Control. The respondents reckoned that pest control was unnecessary on biodiversity roofs. The pollinator expert pointed out that biodiversity roofs would attract both plant-feeding animals and predators, the latter of which could protect plants from overgrazing. Interestingly, the carabid and sunny habitat expert regarded plant-feeding animals as supporters of biodiversity. He said, *"it's good to have many different trophic layers"* that control one another. He explained that e.g. flowering plants use nectars to attract pollinators like butterflies, whose larvae feed on the leaf. Caterpillars could attract birds to green roofs. Furthermore, one respondent noted that no green roofs in Finland had been reported to be invaded by pests, thus direct pest control was not needed on roofs at the moment.

Monitoring Roof Conditions. Half of the interviewees suggested monitoring roof conditions, including substrate moisture, vegetation performance, substrate pH, nutrient condition, organic matter content, drainage, and the physical structures of biodiversity roofs. As the bird expert generalised, *"... monitoring system would be good to have kind of adaptive management to the situation, where you are learning what you're doing, and then try to improve the methods you're using in the management."*

3.2.7 Respondents' Concerns for Biodiversity Roofs

Besides the concerns mentioned in the earlier sections, I here summarise the most frequently mentioned and important concerns that the experts brought up in the interviews (Table 7).

Roof Weight. The respondents regarded roof weight as the biggest concern in the Finnish context, as Finland receives a large amount of snowfall during winter. According to the interviewees, we should first consider roof load capacity for snow and then decide if an existent roof is suitable for greening. Moreover, green roof substrates can absorb moisture during the snowmelt, which also puts weight on roofs. Thus snow and substrate moisture should be paid special attention to in green roof designs.

People's Attitudes. The respondents mentioned people's attitudes towards green roofs now and then. One respondent worried about seagulls. He said, *"That may be a problem that (green roofs) even attract the 'wrong species' and in the 'wrong' numbers possibly. ... Seagulls. Yeah, most people perhaps don't like seagulls nesting on their roofs."* The bird expert said that although some seagull species are endangered species in Finland, the preconception of seagulls might impact people's attitudes towards biodiversity roofs if they increase seagulls' nesting probabilities. One interviewee was concerned about how the past failure of green roofs, e.g. water causes roof leakage, would influence people's opinions about green roofs. Another two participants were concerned about financial issues. One reckoned that big green roofs required more materials and workforce, and the other thought monitoring and irrigating systems were costly. The interviewees thought that these were practical issues that remained to be solved.

Table 7 Interviewees' concerns related to biodiversity roofs.

Concerns	Reasons
Roof weight	1. Green roofs increase the roof load, while snow is already a burden to the roof during winter in Finland. 2. Green roof substrates will absorb moisture during the snowmelt.
People's attitudes	1. People' attitudes can be influenced by what green roofs support. E.g. Gulls in large numbers are often unwanted. 2. Past failure of green roofs can lead to people's unwillingness to install a green roof. 3. Financial issues also influence people's willingness to have green roofs.
The service life span	1. The service life span directly impacts the capacity of green roofs to support biodiversity.
Sudden frost	1. Sudden frosty autumn nights are lethal to green roof vegetation when plants are not ready for the cold.
CO_2 content in green roof ecosystems	1. Plants need oxygen during winter because there are always some activities in the soil throughout the season.
Contamination	1. Possible contamination of topsoil by heavy metals. 2. Gene-pool may be contaminated if introduced plant species are used on green roofs.

The Service Lifespan of Biodiversity Roofs. The pollinator expert was concerned about the lifespan of biodiversity roofs since it directly impacts their capacity to support biodiversity. He noted that fauna could benefit from biodiversity roofs only when they existed for many years, because *"if they (green roofs) support a population of some species, they produce offspring and they can* *disperse in other areas, maybe enhance the local population"* (pollinator expert).

Sudden Frost. The two plant experts were worried about the survival of vegetation during the winter. The moss expert regarded the first winter as a critical time for new biodiversity roofs, because they are *"very vulnerable to cold, to freezing temperature"*. The vascular plant expert reckoned that a low temperature like -15 ˚C without snow troubled biodiversity roofs by freezing the soil, which is a harsh situation for vegetation. Although native plants in Finland have adapted to cold periods, the vascular plant expert was still worried about early frosty autumn nights when plants, especially cultivated plants, are unready for minus degrees. As the two experts concluded, cold tolerance could be a necessary characteristic for plants on biodiversity roofs.

Increasing CO_2 in Green Roof Ecosystems. Interestingly, the vascular plant expert pointed out that plants need fresh air to breathe during winter time. *"If the air is not changing, it will have harmful effects, because there are always some activities in the soil throughout the season,"* explained the expert. According to him, if the carbon dioxide (CO_2) generated in the soil does not go through the system, its content will increase in the soil while the content of oxygen (O_2) will decrease, which harms living things in green roofs.

Contamination. Contamination was another topic brought up by two experts. The soil expert mentioned topsoil and said that there could be a risk that it was contaminated by heavy metals, but no further details were given. Interestingly, the pollinator expert noted that contamination might also happen in gene pools. According to him, we should beware of non-native and invasive species. He took two *Galium* spp. in Finland as an example. *G. verum* is threatened due to the loss of habitats and cross-breeding with its close relative *G. album*, an alien but not invasive species in Finland. Their hybrid, *G. × pomeranicum*, however, has been identified as an invasive species and threatens the survival of *G. verum*.

4 Discussion

In this section, I compare and summarise the results of the literature review and the interviews to conclude what a biodiversity roof could be like under Finnish conditions.

4.1 Model Ecosystems for Finnish Biodiversity Roofs

According to the results of this thesis, sunny and dry habitats, e.g. meadows, dry meadows, esker ridges and rock outcrops, are possible “model ecosystems” to be mimicked on roofs in the Finnish context. First, dry and sunny habitats are relatively well-studied ecosystems in Finland and support a wide range of plants and animals, some of which are red-listed species, e.g. Milky Whitlow-grass (*Draba lacteal*; Rassi et al. 2010, p. 103 and 194). Dry meadows have shown to have high plant species diversity and they are valuable for e.g. granivorous carabids diversity in the urban areas in Finland (Venn et al. 2013). Second, if mimicking these sunny and dry habitats, biodiversity roofs require low maintenance. For the reason, these sunny and dry habitats are relatively unfertile, e.g. nearly all rock outcrops in Finland are nutrient-poor or moderately fertile (Rassi et al. 2010, p. 92), and these dry and sunny habitats, such as meadows on bedrock, do not require management, such as mowing (Venn 2013). Thus, sunny and dry habitats are ideal “model ecosystems” to mimic, in order to create biodiversity roofs with little management.

Although tundra was not mentioned as a “model ecosystem” either in the reviewed papers or in the experts’ responses, the experts mentioned lichen-based and moss-based communities with dwarf shrubs, sedges and grasses many times in the responses. In tundra, dwarf shrubs, sedges, grasses, mosses, and lichens have been shown to have positive interactions with one another (Carlsson & Callaghan 1991), meaning that these plants can be suitable vegetation on roofs. Thus, tundra can be another “model ecosystem” for biodiversity roofs in the

Finnish context.

Plant species of the “model ecosystems” that support fauna, e.g. pollinators, should be favoured on biodiversity roofs. For instance, the drought-tolerant sedums suitable on roofs are important to two butterfly species in Finland that specialise on them. These two species, Apollo (*Parnassius apollo*) and Chequered Blue (*Scolitantides orion*), have a protected status in Finland (Brommer & Fred 1999, Komonen et al. 2008), which means that sedums may even increase conservation values of green roofs in the Finnish context.

Furthermore, plant species at protected status, e.g. some members of *Campanula* and *Antennaria* (See Appendix 4), may benefit from being located on biodiversity roofs that provide open habitats to species that suffer from shading, e.g. Bristly Bellflower (*C. cervicaria*; Eisto et al. 2000). Biodiversity roofs are also beneficial to plant species by providing enough insect pollination, as biodiverse habitats attract pollinators (Ksiazek et al. 2012). This, in return, adds biodiversity value of roofs. Furthermore, sensitive plant species, such as Harebell (*C. rotundifolia*), that response to habitat restoration by increasing population size (Lindborg et al. 2005), could be used as an indicator of biodiversity roof habitat quality.

Microbes from the model ecosystems may help the survival of plants on biodiversity roofs. For instance, the mentioned *Antennaria* species have a mutualism with arbuscular mycorrhizal fungi. This mutualism involves a reciprocal transfer of photosynthates and mineral nutrients (Vega-Frutis et al. 2013), which is a win-win strategy for microbes and plants. However, if and how wanted microbes can establish themselves on biodiversity require detailed studies.

Besides fauna mentioned in the review and the interviews, such as spiders and birds, other animals, such as snails and bats, can also be supported on roofs. For instance, even two rare snail species, *Pseudotrichia rubiginosa* and *Succinella oblonga* were recently recorded on 1.5 metres high green roofs in Finland (Páll-Gergely et al. 2015). Moreover, urban areas and parks in Finland are the most typical foraging habitats for Northern Bat (*Eptesicus nilssonii*) and Brown Long-eared Bat (*Plecotus auritus*; Wermundsen & Siivonen 2008). In addition, Brandt's Bat (*Myotis brandtii*), Whiskered Bat (*M. mystacinus*) and Doubenton's Bat (*M. daubentonii*) that need conservation in Finland occasionally foraged in open/uncluttered space (Wermundsen & Siivonen 2008). As a study in the literature review has shown that *Eptesicus* species were detected feeding on biodiversity roofs in London (Pearce & Walters 2012), biodiversity roofs in Finland could support snails and bats.

4.2 Features that Influence Biodiversity Roofs

4.2.1 Substrates

According to the results of this thesis, substrate heterogeneity is the most significant factor affecting roof biodiversity. First, different substrate materials support different taxa. For example, combinations of different materials, such as crushed brick and crushed demolition aggregates, can be used to mimic various soil types of the most biodiverse ecosystems in Finland to attract various species. Second, heterogeneity in substrate depth seems to support different species. For example, in the literature review, Heim and Lundholm (2014a) and Brenneisen (2006) emphasised the importance of different substrate depths to floral diversity on green roofs. The interviewees also brought up substrate depth heterogeneity, which indicates that various substrate depths should be beneficial to roof biodiversity under Finnish conditions too. However, further research is needed on the effects of substrate depth heterogeneity on biodiversity, especially on faunal diversity that has not been empirically tested at all.

Furthermore, as showed in the results, the ideal roof substrates should be lightweight and well-drained to avoid roof damage due to a too high level of substrate moisture. However, the ideal substrates should also be able to maintain a certain amount of moisture to buffer against drought, as the annual precipitation

Finland receives is 536 mm (World Bank, n.d.). Mineral substrates with small sized particles can be good choices for biodiversity roofs in Finland as they keep moisture well. These results are in line with the previous studies from other parts of the world showing that small sized particles are suitable for dry climate conditions (e.g. Young et al. 2014). Furthermore, both the experts and the studies of the reviewed studies (e.g. Nagase & Dunnett 2011) suggested that a moderate amount of organic matter can be mixed into substrates to enhance the water holding capacity. Yet more empirical work should be done to find the balance between drainage and moisture maintenance of roof substrates.

4.2.2 Plant Species Selection and Greening Methods

When selecting plants on roofs, one should beware of non-native species, even plants from the above-mentioned genera, such as *Campanula*, that can occupy space from native species. For example, some members of genera *Sedum* and *Campanula* may be invasive outside of their native distribution areas, such as *Sedum aizoon* (NOBANIS, n.d. a). For the same reason, some species studied in the reviewed papers are unusable under the Finnish conditions, e.g. Black Medick (*Medicago lupulina*) in the study of Olly et al. (2011) has been recorded as an invasive alien species in Finland (NOBANIS, n.d. b).

Species that have big roots, such as seedlings of woody species, may also be unwelcome on roofs (e.g. Miller et al. 2014). However, avoiding these kinds of species is not unambiguous. E.g. Breckland Thyme (*Thymus serpyllum*), a herb frequently mentioned in the interviews, also has big roots, but it also has a high conservation value, as it is a near threatened species in Finland and it attracts pollinators. Furthermore, tree seedlings have been reported to grow only a few centimetres tall and cause no roof damage before they die (Bates et al. 2013). Thus, it might be that species with big roots like thymes on roofs are suitable for roofs, and therefore they should be studied in details.

Besides ecological also social benefits should be considered when selecting plants for roofs. Some weeds, such as dandelions, are debatable plants on biodiversity roofs, as an interviewee noted that gardeners usually dislike them. However, dandelions can be attractive to pollinators, and their leaves can even produce ethylene that can help ripen seeds of other plants (Pratt 1954). Dandelions thus may actually help keep floral diversity on roofs. Retaining some weeds on biodiversity roofs might be a good option, as long as they do not dominate the whole growing space.

Competition can impoverish plant performance and decrease floral diversity; some species thus perform better in monoculture (Lundholm et al. 2014). Some plants, such as Bearberry (*Arctostaphylos uva-ursi*) that appear on e.g. esker ridges, utilise allelopathy to inhibit the growth and survival of e.g. Heather (*Calluna vulgaris*; Hobbs 1984), a common species on rocks and dry forest heaths in Finland. Therefore, when selecting plant species for biodiversity roofs, one should avoid competitive species, and select plant species that can co-exist well.

Facilitation between plants broadens species options for biodiversity roofs but also has potentials to harm microbes. For instance, ornamental species, such as Chinese Leek (*Allium tuberosum*), may inhibit the growth of microbes when protecting itself and surrounding plants from diseases, by producing an antibacterial substance named allicin that kills microbes (Yin & Tsao 1999). Yet the effects of allicin produced by *Allium* spp. on soil microbes on green roofs has not been studied. This example shows that facilitation between plants, and their impacts on other biodiversity roof features, should be studied in more detail.

The advantages of different greening methods should be made full use of to achieve a fast greening effect and avoid biological invasion. As mentioned in the results, there is a dilemma between ecology and aesthetics, i.e. present methods using non-native species to achieve instant greening may lead to biological invasion, while methods using native species may leave green roofs not green. I think multiple greening methods could be applied on the same roof to support both biodiversity and beauty, for instance, a seed mixture of annual and perennial species can be sown in biodiversity roof substrates, while vegetation mats can be installed to cover part of the roof. Moreover, vegetation mats should be produced from native plants that attract endangered butterflies, such as Orpine (*Sedum telephium*; Komonen et al. 2008).

4.2.3 Supporting Faunal Diversity on Biodiversity Roofs in Finland

Although biodiversity roofs can support carabids, it is still unclear how they shape the distribution of carabids. At the ground level, the abundance and species richness of carabids were found to have no significant differences along a forested urban-rural gradient in the Helsinki metropolitan area, the most urbanised area in Finland (Alaruikka et al. 2002). This phenomenon questions what role biodiversity roofs can play for carabids in the Finnish context, and calls for detailed studies.

Biodiversity roofs may act as habitats for spiders rather than corridors. In the Helsinki metropolitan area, spider diversity has no significant differences across an urban-rural gradient at the ground level but is significantly different at the site level, meaning that habitat structure plays a vital role in supporting spiders (Alaruikka et al. 2002). This is in accordance with the findings of Braaker et al. (2014) who stated that local environmental conditions have more impacts on the diversity of spiders than habitat connectivity at the landscape level. Also, the interviewed spider expert emphasised the heterogeneous vegetation structure on roofs to support spider web building. The variability of vegetation structure could be generated by creating different vegetation layers, such as ground, field and bush layers on roofs.

Planting trees and large bushes has been reported to be the most effective way to enhance bird diversity at the ground level (Fontana et al. 2011). Thus, woodland species, such as Robin (*Erithacus rubecula*), could, at least in theory, be supported on roofs if trees are available. However, in the Finnish context, bird species that prefer short vegetation, e.g. Northern Wheatears, are more threatened than woodland species. To support species like the Northern Wheatear, nest boxes can be installed on green roofs, as they have been shown to enhance bird diversity in gardens (Shwartz et al. 2014).

The breeding success of birds is still a problem on green roofs, although green roofs are free from ground predators, such as Red Fox (*Vulpes vulpes*), the exclusion of which has been proved to reduce chick mortality at the ground level (Rickenbach et al. 2011). However, avian predators are still a threat to bird young on biodiversity roofs, as they have been shown to be the main nest predators of birds in urban areas (Jokimäki & Huhta 2000). Plants that provide shelters and high spots where mature birds can scan avian predators, therefore, should be provided on roofs to enhance bird breeding success.

Different bird species have different requirements for connectivity between biodiversity roofs and other green spaces. The fledglings of the above-mentioned wader species, *Vanellus vanellus*, leave the nest soon after hatching and learn to find their own food quickly. Starved fledglings of *V. vanellus* have high risks of predation (Schekkerman et al. 2009); thus, food availability on green roofs and the connectivity to other feeding habitats are crucial to the fledglings of waders. Fledglings of gulls, however, are fed by their parents that can fly a long distance to bring back food. This means that food availability on breeding roofs and the connectivity to other green spaces are less important to their survival, according to my results. Hence, connectivity from the biodiversity roof to other green spaces should be ensured if the roof is targeted to support species dependent on food availability at near distance.

4.2.4 Roof habitat characteristics influence faunal diversity.

Besides connectivity to other green spaces at the landscape level, green roof size per se may contribute to the diversity on roofs. However, the association between the habitat size and biodiversity may not be straightforward. At the ground level, the biodiversity of a green space is usually positively associated with the increasing area of the green space (Jones & Leather 2012). Regional animal populations at the ground level strongly depend on the presence of large green space patches rather than a network of small and large patches, perhaps due to the continuous presence of large green patches and sources (Connor et al. 2000). Yet the size of a biodiversity roof is not necessarily a fundamental determinant to all animal groups that it supports. For instance, the literature review of this study showed that green roof size has little influence on arthropod community, as small green roofs can support urban arthropod biodiversity if only vegetation offers suitable habitats for them (e.g. Ksiazek et al. 2012, Braaker et al. 2014). This may result from that green roofs supports fauna with high mobility in general. If and how green roof size influences biodiversity require detailed studies.

Although in my results, extra elements, such as deadwood and insect hotels, were recommended to create heterogeneity and support fauna on roofs, it can be unpredictable what species these elements will attract. A study in Canada reported that insect hotels supported both bees and wasps, but wasps were more abundant than bees and might outcompete bees (MacIvor & Packer 2015). If we support specific species or taxa on biodiversity roofs, more detailed studies about extra elements are needed.

Planning biodiversity roofs requires long-term thinking, as old roofs presumably support biodiversity better than young, lately established roofs. At the ground level, site age of urban green spaces has a positive relationship with the diversity of carabids, leafhoppers, spiders, and Lepidoptera (i.e. butterflies and moths; Saarikivi et al. 2010, Jones & Leather 2012). One reason for this is that succession in old habitats is at a more final stages than in younger sites (Saarikivi et al. 2010). However, succession can also impoverish vegetation and decrease habitat heterogeneity (Small et al. 2006), especially on green roofs with shallow substrates (Gabrych et al. 2016), meaning that food availability on green roofs may decrease over time and support limited faunal diversity (Dunnett et al. 2008b). Biodiversity roofs thus should be planned with a long service life span and elements that support roof biodiversity in a long run.

4.2.5 Managements for Biodiversity Roofs

Installing automatic irrigation systems on biodiversity roofs has both pros and cons, according to the results of this study. Automatic irrigation systems can be costly and add weight to roofs, especially when monitoring systems are also installed. Comparing to automatic systems, manual irrigation hardly adds equipment to roofs and involves fewer concerns about roof weight, which leaves more roof load for green roof substrates. Furthermore, ideal biodiversity roofs aim at becoming self-sustaining ecosystems and require little irritation (Butler & Orians 2011). Biodiversity roofs might be less likely to achieve this goal with the presence of automatic irrigation systems. Hence, the benefits of using automatic irrigation systems are still questionable on biodiversity roofs and needs empirical studies.

Well-designed small ponds on roofs could be another option to support water supply for plants. Besides, they may attract semi-aquatic fauna, such as dragonflies. "Wetland green roofs" in South Korea and Vietnam are similar to small ponds and have shown to support wetland plants on roofs in the experiments (Song et al. 2013, Thanh et al. 2014, Van et al. 2015). Although the interviewees were concerned that a small pond might dry up during dry seasons, even temporary ponds can still contribute to urban biodiversity, as shown by e.g. Nicolet et al. (2004). They reported that temporary wetlands in the U.K. supported wetland plants and macroinvertebrates, some of which were rare or uncommon species. Yet the temporary ponds involved in their study were at least 25 m^2 at the ground level. More research is needed to study whether ponds can support biodiversity on roofs and what size they should at minimum be.

Manually removing unwanted species instead of mowing can be the best weeding method for biodiversity roofs. Mowing has been considered as a method to weed competitive species since it can reduce the cover of alien species at the ground level (Maron & Jefferies 2001). However, mowing negatively impacts invertebrate diversity at the ground level, as it decreases vegetation complexity and food availability, and can also directly kill invertebrates (Saarinen et al. 2005, Sattler et al. 2010, Jones & Leather 2012, Venn & Kotze 2014). By manually removing competitive species, these disadvantages can be avoided.

Organic fertiliser is a top choice if plants perform poorly. Fertilisation has been shown to improve the primary production of urban green spaces and increase resources for animals (Sandström et al. 2006). Organic fertiliser releases nutrients slowly, which is an important aspect as nutrient leachates from green roofs can contaminate surface water (Kuoppamäki & Lehävirta 2015). To avoid water contamination, a close system can be designed, i.e. the runoff from biodiversity roofs is collected and used as water supply for biodiversity roofs themselves.

Besides the negative impacts of trampling on spiders mentioned by one respondent, trampling also influences carabids. A study by Niemelä and Kotze (2009) showed that only a few carabid species colonised in highly disturbed urban areas at the ground level. Also, Grandchamp et al. (2000) showed that some carabid species in Finland, such as *Carabus hortensis*, are sensitive to trampling. Trampling thus should be avoided on at least some areas of a biodiversity roof to support both spiders and carabids.

The results of this study suggest that some birds but not insects can cause problems to biodiversity roofs, especially their droppings. Except the problems described in the results, bird droppings can benefit unwanted species on biodiversity roofs. For instance, Scot Pine (*Pinus sylvestris*), a species widely planted in Finland, grows better with than without bird droppings (Tomassen et al. 2005). Moreover, attracting gulls that were frequently mentioned in the interviews may cause people's negative attitudes towards biodiversity roofs in the Finnish context, as gulls are becoming more and more aggressive to people in e.g. Helsinki by robbing food (Heikkilä 6.7.2015, Vuorio 15.7.2016). Yet there is a lack of specific studies about problems caused by faunal species that biodiversity roofs support.

4.2.6 Possible Obstacles to Keep Biodiversity Roofs in Finland

Although generally, people show positive attitudes towards green roofs, more on-site studies are still necessary to dig out information about people's attitudes towards biodiversity on green roofs. First, the methodology can influence the result of a survey. For example, an image survey and an on-site survey on decaying log resulted in different outcomes (Edwards et al. 2012, Hauru et al. 2014). Four out of the six studies on people's attitudes reviewed in this thesis, however, were done by using synthetic images, and only one was an on-site study. Furthermore, the images used in the four studies could not fully illustrate a biodiversity green roof, since they only involved flora, but not fauna. Fauna, such as arthropods, are rarely a priority for conservation due to the negative attitudes of most urban dwellers and even some ecologists (Bjerke & Østdahl 2004, Madre et al. 2013). Hence, more on-site studies are needed to reveal the perceptions and opinions of people of biodiversity roofs.

The financial cost is sometimes an obstacle to installing and maintain biodiversity roofs, according to the result of this thesis. For example, entrepreneurs were unwilling to install green roofs in business sites, since they had to pay the bills (Snep et al. 2009). For the same reason, the interviewees were worried about people's willingness of installing biodiversity roofs on their own houses. How to motivate entrepreneurs and people to install biodiversity roofs, therefore, requires more investigation.

Concern about roof weight is another obstacle for installing biodiversity roofs. Therefore, light-weight substrates were suggested in both the literature (e.g.

Bousselot et al. 2011) and in the interviews. However, the interviewees were still concerned about roof weight under Finnish conditions because of a load of snow in winter and snowmelt in early spring. One solution could be assessing roof load capacity to ensure that it can carry the possible load by snow.

5 Conclusions

Dry meadows and tundras can be regarded as Finnish “model ecosystems” for biodiversity roofs in general. Native species from the genera *Sedum*, *Campanula*, *Antennaria*, and *Thyme* are ideal plants for biodiversity roofs in the Finnish context due to their ability to support even rare invertebrates. Plants considered as weeds on the ground level, such as dandelions, can support biodiversity on green roofs only if they are not too competitive species. Combining multiple methods of establishing plants on the same roof can be a solution to achieve “instant greening effects” with only native species.

In the Finnish context, light-weight, good drainage, and small particle sized are relevant factors in selecting substrate materials for biodiversity roofs. Substrate heterogeneity is a key to biodiversity on green roofs, as biodiversity roofs need diverse substrate characteristics to support different flora, fauna and microbes.

An ideal biodiversity roof in the Finnish context should support invertebrates, birds, and bats. The habitat quality is a key to the diversity of fauna, such as carabids and spiders. The connectivity between other green spaces may help fauna, e.g. pollinators. To support fauna on biodiversity roofs, extra elements, such as insect hotels and deadwood, can be used to provide nesting habitats as well as feeding habitats.

Roof structural characteristics (i.e. roof height, size, slope, direction, location, and age) impact biodiversity. Roof height in the Finnish context has little influence on roof accessibility to birds and bats, but it might be that faunal diversity is lower on a biodiversity roof than a green space at the ground level. The association between roof size and biodiversity is not straightforward, while the connectivity between a biodiversity roof and other green spaces is crucial to fauna, such as pollinators. Roof slope determines the technique that should be used to build a biodiversity roof; slope also creates different microclimates on a roof and possibly increase biodiversity. The surrounding environment impacts the microclimate, especially the sun exposure and wind, the latter of which may strongly influence roof biodiversity in Finland. Old roofs generally support higher biodiversity than young ones, but succession may also impoverish roof vegetation over time and decrease roof biodiversity.

Management is still necessary to help biodiversity, although a biodiversity roof aims at being self-sustaining eventually. First, irrigation is demanded at the establishment phase and during extreme weather events. Small ponds are a possible option for irrigation. Second, manual removal of unwanted species is a good choice for weeding when competitive species appear on biodiversity roofs. Third, fertilisation is required if plants perform poorly. In this case, organic fertiliser is a top priority, but the runoff from biodiversity roofs still needs to be collected and used for irrigation to avoid surface water contamination.

People have generally positive attitudes towards green roofs, but their preferences for green spaces and willingness to install green roofs are not directly impacted by biodiversity. To the current knowledge, people's attitudes towards green roofs were studied with only plants but not fauna. More on-site studies should be done on people's attitudes towards green roofs. The financial cost and the concern about roof load capacity are two obstacles influencing people's willingness to install biodiversity roofs. How to motivate people remains to be studied.

6 Personal Reflection

I think the method used for the literature search generally hit highly relevant articles in the Web of Science and the Scopus. The keywords used in "Advanced Scholar Search" of Google Scholar ("green roof" AND "biodiversity" - stormwater - energy), however, may have left out some relevant articles, since green roof performance, stormwater, and energy interact with one another. Tracing references from the searched relevant articles might have involved personal interests and have been subjective.

I felt that the most part of the interviews went smoothly. I started new questions when some experts who were less outgoing stopped talking for around half minute. I, however, felt unsure whether some of them had really finished their answers when I listened to the recording after the interviews. Sometimes the experts explained their ideas with gestures that cannot be recorded in the tape recorder. Luckily those gestures were so impressive that I was always able to think up when I was listening to the recording. I felt I got interesting and informative data from the eight interviews.

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Appendices

Appendix 1 Information of reviewed 34 Review papers.

Papers	Subjects
Baumann & Kasten 2010	birds, e.g. Vanellus vanellus, Charadrius dubius
Brenneisen 2006	birds, e.g. Alauda arvensis
Butler et al. 2012	plants, e.g. Sedum sp.
Caneva et al. 2015	plants, e.g. Achillea maritima, Ruta chalepensis
Carlisle & Piana 2015	plants, e.g. Schizachyrium scoparium, Melilotus officinalis
Caron et al. 2013	organic matters, e.g. peat, bark
Catalano et al. 2013	substrates: loamy-sandy substrates, sandy gravel and natural top soil
Coffman et al. 2014	plants, e.g. Aquilegia canadensis, Aster divaricatus
Cook-Patton & Bauerle 2012	plants, e.g. Sedum sp.
Cook-Patton 2015	plants e.g. Oenothera biennis
Damas et al. 2010	plants, e.g. Dianthus carthusianorum, Sedum sediforme
Davies et al. 2010a	plants, e.g. Astelia banksii; animal, e.g.Bedellia psamminella
Dunnett 2010	substrates: brick rubble, crushed concrete
Fassman & Simcock 2012	substrates : expanded clay, shale, or slate in Europe and North America; crushed lay bricks, concrete and fly ash in the U.K.; natural volcanic material, such as pumice and zeolite in New Zealand and Pacific Northwest of the U.S.A.
Fernandez-Cañero & Conzalez-Redondo 2010	bird, e.g. Charadrius dubius
Francis & Lorimer 2011	biodiversity benefits and limitations, e.g. habitats for spiders, beetles, wasps, ants and bees; but species do not disperse easily on roofs; and other issues
Gedge & Kadas 2005	plants e.g. Sedum telephium, animals e.g. Alauda arvensis
Gedge 2003	birds, e.g. Phoenicurus ochruros
Gedge et al. 2010	invertebrates, e.g. Polistichus connexus

Appendix 1 Information of reviewed 34 Review papers (Continued).

Papers	Subjects
Grant 2006	plants, e.g. Vicia cracca, Viola tricolor
Ishimatsu & Ito 2013	blace redstart (Phoenicurus ochruros), invertebrates
Kadas 2007	animals, e.g. Bombus lapidaries; substrate structural diversity
Kinlock et al. 2015	plants, e.g. Sedum sp.
Lorimer 2008	birds, e.g. Phoenicurus ochruros
Lundholm 2006	the urban cliff hypothesis
Lundholm 2015a	maintenance, e.g. weeding; impacts of wilderness, e.g. undesirable use by rats, pigeons; and other issues
MacIvor & Ksiazek 2015	invertebrates, e.g. spiders, assassin and damsel bugs, dragonflies, solitary wasps
McGuire et al. 2015	bacteria and fungi in green roofs
Oberndorfer et al. 2007	plants: Sedum sp.; ecosystem services, e.g. storm-water management
Ranalli & Lundholm 2008	biodiversity and ecosystem functioning
Sutton 2014	aesthetics and roof greening
Sutton 2015	biodiversity and other ecosystem functions
Williams et al. 2010	substrates, plants, e.g. plants with soft or fleshy leaves, such as Carprobrotus sp., are potential species for green roofs in Australia
Williams et al. 2014	biodiversity conservation

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers.

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Bates et al. 2013	plants	e.g. *Papaver rhoeas, Viola tricolor*	broken bricks, concrete and sand	seeded	no weeding	U.K.
Bates et al. 2015 a	plants	e.g. *Centaurea cyanus, Prunella vulgaris*	crushed brick, crushed demolition aggregate, solid municipal waste incinerator bottom ash	seeded	-	U.K.
Bates et al. 2015 b	plants, organic matter conttent	wildflower, e.g. *Centaurea cyanus, Prunella vulgaris*, *Sedum acre*	concrete, pebbles, brick, ceramics, sand	seeded	-	U.K.
Baumann 2006	animals	birds, e.g. *anellus vanellus, Charadrius dubius*	-	-	-	Switzerland
Benvenuti 2014	plants	e.g. *Anthemis maritima, Helichrysum italicum*	perlite, lapil, pumice, zeolites, peat, a slow release fertilizer	planted	slow release fertilizer	Italy
Benvenuti & Bacci 2010	plants	e.g. *Allium carinatum, Centaurea cyanus*	lapillus, pumice stone, zeolite, peat, and a slow release fertiliser	planted	irrigation after 3 days of elevated osmotic pressure	Italy

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Boivin et al. 2001	plants	e.g. *Ajuga reptans, Armeria maritima*	mineral aggregates , organic matter , but no details	planted	watered manually four times during the summer dry periods of 1995 to 1997	Canada
Bousselot et al. 2011	plants	e.g. *Allium cernuum, Sedum acre*	peatmoss, perlite, vermiculite	planted	irrigation	U.S.A
Braaker et al. 2014	animals	carabids, spiders, weevils, bees	-	-	-	Switzerland
Bures 2013	substrates	-	concrete,compost or crushed building wastes	-	-	Spain
Burgress 2004	animals	e.g. *Carduelis cannabina, Turdus philomelos*	-	-	-	U.K.
Butler & Orians 2009	plants	e.g. *Agastache rupestris, Asclepias verticillata*	shale aggregates, sand, leaf compost	planted	controlled release fertilizer within a week of planting, irrigation after 2 weeks without rain	U.S.A.
Butler & Orians 2011	plants	Sedums, *Agastache rupestris, Asclepias verticillata*	expanded shale aggregate, sand, leaf compost	planted	irrigation after 2 weeks without rain	U.S.A.

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Cao et al. 2014	plants, biochar	wheat as indicator species	scoria, biochar,coir, coconut fiber	seeded	controlled release fertilizer (2.4 g Green Jacket 16.5 N: 4.1P: 9.6 K, Debco Pty Ltd)	Australia
Chen et al. 2015	plants	e.g. *Lygodium japonicum, Schefflera odorata*	rubble, peat, perlite vermiculite, mature organic fertiliser, bark surface	seeded	-	Taiwan
Coffman 2007	plants, animals	plants e.g. Junegrass; animals e.g. Carabidae	expanded slate, sand, compost, peat, dolomite	planted	-	U.S.A
Coffman & Waite 2011	plants	e.g. *Daucus carota, Leucanthemum vulgare*	expanded slate, sand, compost, peat, dolomite	planted	irrigation	U.S.A.
Colla et al. 2009	animals	Bees (*Apoidae*), e.g. *Bombus bimaculatus*	-	seeded	-	Canada
Davies et al. 2010b	plants, animals	plants e.g. *Oligosoma aeneum*, animals e.g.Lepidoptera	-	planted	irrigation	New Zealand
De-Ville et al. 2015	substrates	-	brick, light expanded clay aggregate, bark, coir	-	-	U.K.

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Dunnett & Nolan 2004	plants	e.g. *Dianthus deltoides*	light expanded clay granules, green waste compost, medium loam	planted	two subplots: one received supplementary watering, the other received no irrigation	U.K.
Dunnett et al. 2008a	plants	e.g. *Armeria maritima*	light expanded clay granules, green waste compost, medium loam	planted	irrigation	U.K.
Durhman et al. 2007	plants	e.g. *Phedimus spurious, Sedum acre*	heat-expanded slatesand, peat, dolomite, composted yard waste, composted turkey litter	planted	irrigation, but no irrigation during the second growing season	U.S.A.
Dvorak & Volder 2013	plants	e.g. *Lampranthus spectabilis, Malephora lutea*	FLL-compliant growth media (Rooflitewdrain, Skyland, Avondale, PA, USA)	planted	no irrigation	U.S.A.
Emilsson & Rolf 2005	plants, vegetation establishment	e.g. *Sedum album, Sedum acre*	natural soil mixture improved by the addition oflava rock, expanded clay, organic material and clay	pre-made vegetation mats, plug plants	-	Sweden
Emilsson 2006	plants	e.g. *Sedum album, Sedum acre*	recycled roof tiles	planted	-	Sweden
Emilsson 2008	plants, substrates	e.g. *Sedum album, Sedum acre*	clay, limestone, roof tiles, sand, peat	planted	fertilization in spring	Sweden

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Farrell et al. 2012	plants, substrates	e.g. *Sedum pachyphyllum, Carpobrotus modestus*	scoria, roof tile, bottom ash	planted	slow release fertilizer	Australia
Farrell et al. 2013	plants	e.g. *Arthropodium milleflorum, Brachyscome multifidi*	scoria, coir	planted	irrigation	Australia
Fernandez-Cañero et al. 2013	People's attitudes	-	-	-	-	Spain
Getter & Rowe 2009	plants	e.g. *Sedum cauticola*	details in Getter & Rowe 2008, which article is unavailable	planted	controlled release fertiliser	U.S.A.
Getter et al. 2009	plants	e.g. *Sedum kamtschaticum, Sedum pulchellum*	-	planted	weeding	U.S.A.
Graceson et al. 2014	plants	e.g. *Sedum* sp.	crushed brick, tile, composted green waste	seeded	no irrigation	U.K.
Harp et al. 2015	plants	e.g. *Achillea millefolium, Phaseolus vulgaris*	peat, perlite, shale, compost, sand	-	-	U.S.A.
Heim & Lundholm 2014 a	plants	e.g. *Polytrichum commune,Danthonia spicata*	-	planted	-	Canada
Heim & Lundholm 2014 b	plants	e.g. *Festuca rubra, Sedum acre*	-	planted	irrigation for the newly established vegetation	Canada

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
John et al. 2014	fungi	mycorrhizal& root endophytic fungi	peat-vermiculite	-	-	Canada
Jones 2002	animals	e.g. Coleoptera, Hemiptera, Aranaea	-	-	-	U.K.
Jungels et al. 2013	people's attitudes	-	-	-	-	U.S.A.
Kadas 2006	animals	spiders, e.g. *Pardosa agresits*	-	-	-	U.K.
Klein & Coffman 2015	plants	e.g. *Euphorbia maculate, Portulaca maculate*	-	plugged, seeded	irrigation	U.S.A.
Köhler 2006	plants	e.g. *Poa compressa, Festuca ovina*	sandy garden soil, expanded clay	planted	irrigation	Germany
Ksiazek et al. 2012	plants, animals	plants, e.g. *Allium cernuum*; poliinators, e.g.*Bombus* sp.	-	-	-	U.S.A.
Ksiazek et al. 2014	plants	e.g. *Allium cernuum*	-	-	-	U.S.A.
Latocha & Batorska 2007	plants	e.g. *Juniperus procumbens*	-	-	-	Poland
Lee et al. 2014	people's attitudes	-	-	-	-	Australia
Liu et al. 2012	plants	e.g. *Kalanchoe*	-	planted	-	Taiwan

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Loder 2014	People's attutudes	-	-	-	-	U.S.A. & Canada
Lu et al. 2015	plants	*Sedum lineare*	perlite, sand, vermiculite, ceramisite, crushed limestone, peat moss soil	planted	-	China
Lundholm et al. 2010	plants	e.g. *Poa compressa, Sedum acre*	crushed brick, peat, perlite, sand, and vegetable compost	planted	-	Canada
Lundholm et al. 2014	plants	e.g.*Sagina procumbens*	-	planted	weeding	Canada
Lundholm et al. 2015	plants	e.g. *Campanula rotundifolia*	-	planted	weeding	Canada
Lundholm 2015b	plants	e.g. *Sagina procumbens, Spergularia rubra*	-	planted	-	Canada
MacIvor & Lunholm 2011	animals	e.g. *Camponotus* sp.	-	-	-	Canada
MacIvor et al. 2011	plants	dryland plants e.g.*Empetrum nigrum*; wetland plants e.g. *Vaccinium macrocarpon*	crushed brick, peat, perlite, sand, and vegetable compost	planted	weeding	Canada
MacIvor et al. 2013	plants	e.g. *Rudbeckia hirta*	FLL media (porous, inert aggretate, composted green waste organic material, sand)	seeded	irrigation	Canada
MacIvor et al. 2014	plants, animals	bees e.g.*Lasioglossum* spp.; plants, e.g. *Sedum* spp.	-	-	-	Canada

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Madre et al. 2013	animals	arthropods, e.g. *Mangora acalypha* (spider)	-	-	-	France
Madre et al. 2014	plants	e.g. *Plantago lanceolate*	-	-	-	France
McGuire et al. 2013	fungi	e.g. Ascomycota, Glomeromycota	-	-	-	U.S.A.
Miller et al. 2014	plants	e.g. *Arctostaphylos uva-ursi*	crushed brick, peat, perlite, sand, and vegetable compost	-	-	Canada
Molineux et al. 2009	plants, substrates	*Plantago lanceolata*	crushed red brick, clay pellets, paper ash	-	-	U.K.
Molineux et al. 2014	microbial community	arbuscular mycorrhizal fungi (AMF)	crushed brick, concrete, organic matter	seeded	irrigation	U.K.
Molineux et al. 2015	microbial community	arbuscular mycorrhizal fungi (AMF)	crushed brick, concrete, organic matter	seeded	-	U.K.
Nagase & Dunnett 2010	plants	e.g. *Silene uniflora*	crushed brick or tile	planted	irrigation	U.K.
Nagase & Dunnett 2011	plants	e.g. *Allium schoenoprasum*, *Limonium latifolium*	crushed brick, organic matter	planted	two treatments: additional irrigation / no irrigation	U.K.

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Nagase & Dunnett 2012	plants	e.g. *Leontodon hispidus*	crushed brick or tile	planted	-	U.K.
Nagase & Dunnett 2013 a	plants	annual plants, e.g. *Adonis aestivalis*, *Anagallis arvensis*	commercial green roof substrate (Zinco)	seeded	irrigation	U.K.
Nagase & Dunnett 2013 b	plants	e.g. *Allium flavum*	crushed brick, organic matter	planted	weeding	U.K.
Nagase & Nomura 2014	plants, animals	plants e.g. *Acorus gramineus*; animals, e.g. *Argiope*	-	-	-	Japan
Nagase et al. 2011	animals	butterflies, e.g. *Graphium sarpedon*	-	-	-	Japan
Nagase et al. 2013	plants	e.g. *Allium schoenoprasum, Armeria juniperifolia*	crushed brick	planted	drip irrigation, irrigation once a week during	U.K.
Narigon 2013	animals	birds, e.g. *Chaetura pelagica*	-	-	-	U.S.A.
Nektarios et al. 2015	plants	*Sedum sediforme*	sandy loam soil, pumice, perlite, compost, and zeolite	planted	irrigation, hand weeding twice throught the experiment	Greece
Olate et al. 2011	plants	e.g. *Glandularia berteri*	-	planted	drip irrigation	Chile
Olly et al. 2011	plants	e.g. *Sedum acre*	-	seeded	no irrigation, no fertilisation	U.K.

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Ouellette et al. 2013	plants	tomato	-	planted	drip irrigation was used in the growing season	U.S.A.
Papafotiou et al. 2013	plants	*Aromatic Xerophytes*	compost,soil,perlite, peat	planted	irrigation	Greece
Paraskevopoulou et al. 2015	plants	*Arthrocnemum macrostachyum, Halimione portulacoides*	soil, pumice , grape marc compost or peat	planted	irrigation	Greece
Pearce & Walters 2012	animals	bats, e.g. *Pipistrellus pipistrell*	-	-	-	U.K.
Pérez et al. 2015	plants	e.g. *Sedum rupestre*	-	planted	-	Spain
Price et al. 2011	plants	e.g. *Antennaria plantaginifolia*	recycled Stalite Permatill fines, composted worm	planted	irrigation	U.K.
Rahman et al. 2015	People's attitudes	-	-	-	-	Malaysia
Raimondo et al. 2015	plants	*Arbutus unedo, Salvia officinalis*	lapillus, pomix, zeolite, peat	planted	irrigation	Italy

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Razzaghmanesh et al. 2014	plants	e.g. *Carpobrotus rossii*, *Lomandra longifolia*	crushed brick, scoria, coir fibre, and composted organics	planted	irrigation	Australia
Rowe et al. 2012	plants	e.g. *Phedimus spurius*	heatexpanded slate, sand, peat	planted	irrigation in year1, but no additional watering in years 2	U.S.A.
Rumble & Gange 2013	soil microarthropods	e.g. crushed brick, organic matter	-	planted	-	U.K.
Schneider et al. 2014	plants	e.g. *Acantholimon acerosum*	expanded shale, compost	planted	irrigation	U.S.A.
Schrader & Böning 2006	soil formation	-	-	-	-	Germany
Snep et al. 2009	People's attitudes	-	-	-	-	Netherland
Snep et al. 2011	animals	butterflies, e.g. *Aricia agestis*	-	-	-	Netherland
Sutton 2013	plants, temperature	e.g. *Bouteloua curtipendula*	-	-	-	U.S.A.
Tan & Sia 2005	plants	e.g. *Furcraea foetida*	Mixture of Seramis, Leca® Chips and Compost, or commercial products	planted	irrigation	Singapore

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
Tan & Sia 2009	plants	e.g. *Cyanotis barbata*	-	-	-	Singapore
Thuring & Dunnett 2014	plants	e.g. *Sedum* spp.	-	-	-	Germany
Thuring et al. 2010	animals	e.g. *Sedum album*	expanded clay, expanded shale	planted	irrigation	U.S.A.
Tonietto et al. 2011	plants	bee, e.g. *Lasioglossum anomalum*	-	-	-	U.S.A.
Van Mechelen et al. 2014 a	plants	e.g. *Plantago coronopus*	-	-	-	France
Van Mechelen et al. 2014 b	plants	e.g. *Brachypodium retusum*	-	-	-	Framce
Van Mechelen et al. 2015	plants	e.g. *Tripleurospermum maritimum*				6 European Countries, e.g. U.K.
VanWoert et al. 2005	plants	*Sedum* spp., e.g. *S.pulchellum*	heat-expanded slate, sand, peat,dolomite, composted yard waste	seeded	-	U.S.A.
Vestrella et al. 2015	plants	e.g. *Armeria maritima*	brick fragements, organic matter	planted	irrigation	Spain

Appendix 2 Information of substrates, green roof formation, and maintenance of reviewed 108 research papers (Continued).

Papers	Study subjects	Examples of studied species	Substrates	Formation of Roof	Maintenance	Country/ Region
White & Gatersleben 2011	People's attitudes	-	-	-	-	U.K.
Wolf & Lundholm 2008	plants	e.g. *Rhodiola rosea, Campanula rotundifolia*	-	planted	-	Canada
Yuen & Wong 2005	People's attitudes	-	-	-	-	Singapore
Young et al. 2014	plants	e.g. *Lolium perenne*	brick, organic matter	seeded	irrigation	U.K.
Zhang et al. 2014	plants	e.g. *Allium senescens*	vermiculite, peat, sand, pumice	planted	-	China
Zhao et al. 2014	plants, substrates	e.g. *Sedum hispanicum*	shale, perlite, expanded clay, sandstone, rooflite	-	-	U.S.A.

Appendix 3 Questionnaire

Interview on Urban Biodiversity on Green Roofs

1. Do you know what a green roof is? Have you ever visited a green roof? What kind of biodiversity could be supported or enhanced via green roofs in Finland?

In the following questions, I will ask you about green roof structures that might support biodiversity. In your answers, you can either focus on biodiversity in general or on specific taxa.

2. How should a green roof be constructed to support biodiversity (or your focal taxa) in Finland? Let's focus on the habitat on the roof instead of the whole landscape.

3. Are there any "model ecosystems" in Finland or nearby areas that could be mimicked to support biodiversity or important taxa on green roofs?

4. How to make a green roof attractive to animals?

5. How to take climate change into account in supporting biodiversity on green roofs?

6. What kind of roofs can be suitable to be converted into biodiversity green roofs?

7. Are there any lethal issues concerning possible roof structures as regards the focal biodiversity?

8. What materials could be considered as growing substrates or “soil” to enhance the biodiversity on green roofs in Finland?

9. How should substrate characteristics, such as substrate depth, particle size, organic matter content, be taken into consideration to support biodiversity? Anything else?

10. Is there anything else, except growing substrates, that can be taken into account to enhance or support biodiversity? Are there any other possible structures that can be brought to the roofs to support biodiversity?

11. What plant species would be ideal to support biodiversity on green roofs in Finland? How to support the persistence of these species?

12. In what way(s) should the vegetation be installed on green roofs?

13. Is irrigation necessary to maintain vegetation on green roofs? How should we irrigate? Is there any threshold for irrigation frequency?

14. Is it necessary to retain water underneath the substrate in order to support biodiversity? Are small ponds on roofs needed for water supply? Is there anything else about water availability and retention related to biodiversity on green roofs that you want to express here?

15. Is there any other management or intervention that is needed to support biodiversity or the focal taxa on green roofs?

16. Is it necessary or even possible for green roofs to provide habitat for breeding of fauna? How can we avoid that a green roof becomes a sink/trap habitat?

17. Is there any harm for vegetation if we support birds/spiders/pollinators/carabids or any other fauna on green roofs? Are there any animal or plant species that should be avoided?

18. Do microbes in growing substrates influence green roof biodiversity? How?

19. What microbes are wanted on roofs? Are there any unwanted microbes? How can we help wanted microbes survive on roofs?

20. What are the crucial factors for microbial activity on roofs that influence plant growth?

Thank you very much for your time and help! ・

Appendix 4 Some protected plant species from the genera mentioned by the interviewees.

Species	Conservation status	The bases / reason for conservation
Bristly Bellflower (*Campanula cervicaria*)	vulnerable	Smaller seeds and lower germination through self-pollination than insect pollination, and suffers from shading (Eisto et al. 2000)
Harebell (*C. rotundifolia* ssp. *gieseckiana*)	near threatened	sensitive to both the degradation of habitat quality (Lindborg et al. 2005)
Mountain Everlasting *(Antennaria dioica*)	near threatened	*Antennaria* spp. are dioecious plants, i.e. male and female flowers are separated. *Antennaria* spp. are sensitive to habitat fragmentation due to biased sex ratio and pollen limitation in small populations (Öster & Eriksson 2007).
Woolly Pussytoes *(A. lanata*)	near threatened	
Antennaria nordhageniana (*A. nordhageniana*)	vulnerable	